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THE RATING OF ELECTRICAL MACHINERY.

BY JESSE B. LUNSFORD, MEMBER.*

The author predicts the possibility of saving one-half the weight of shipboard electrical machinery, the saving of weight being accompanied by a saving in cost.

This article is the first of a series of four which delineate a plan for the development of lightweight electrical machinery. The steps recommended are similar to those the author used most successfully in guiding the development of heat and flame resisting cable. He proposes that obsolescent methods of electrical machinery design must be enlivened; that recent improvements in insulating materials have not been fully utilized. He bases his diagnosis on the exposure of present design standards and suggests better yardsticks together with cooperative endeavor.

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PART I—BIG LITTLE DYNAMOS.

Objectives.

"Temperature rise," as applied to the rating of electrical machinery, has been discussed over so long a period of time, so often, so learnedly, and by such eminent authorities, that any further ventilation of the subject could be merely aggravating. An author who dares to add to the writings on this question should be compelled to explain exactly *why* he does so, to state specifically *what* he hopes to accomplish thereby, and to explain in detail *how* he proposes to go about it. Concurring whole-heartedly in such restrictions, this author will discuss the subject from all these angles; not with the attitude of "telling" anyone anything, but rather "asking to know."

First, as to *why* the author writes when a surplus of material is already at hand. The answer is "questions," lots of them. Whenever, amid lush surroundings, growth is too slow, or there is starvation in the midst of plenty, someone is bound to wonder and get ideas. The author is no exception. The reader is forewarned; this is agitation.

Second, as to *what* is the objective. It is to further the development of lighter-weight electrical machinery and equipment for U. S. Naval vessels. It is to secure more horsepower from the same machinery weight, to grow "bigger" little dynamos.

Third, as to *how* such growth is to be urged, sponsored, fostered, induced, provoked, or otherwise caused to be brought about. This is, of course, the big hitch; but there is always a way. If one method fails, try another. Several suggest themselves; if these are not enough, there may be others. All methods do, however, possess one thing in common; they are based upon *asking questions*.

Methods of Approach.

One question concerns the general apathy so long abroad in this field. Perhaps the importance of the available information was not realized; perhaps it was not put up in an appetizing way; perhaps it was not easily assimilable. It may, therefore, be more profitable to add some ferment to that already great store of technical food, to break it down into more digestible form; to interpret

it and " sell " it, as it were; rather than merely to go along blindly gathering up more.

Another question about some of our older conceptions; just how many of them are true in the light of present-day knowledge, and how much is merely " carry-over " from the early days? Don't answer now, there will be lots of chances to answer later, on very specific questions; this is merely by way of prelude, to indicate the general trend.

As a beginning, it is necessary to establish some base, some common understanding of general principles. With this in mind, and as a start, the author has prepared and hereby submits, as a target for criticism, an explanation of the relationship of insulation to electrical size ratings. In it there is an attempt to explain the subject to himself; using, as befits the occasion, the simplest and most non-technical language possible.

Since a non-technical explanation means using many little words instead of a few big words, one's thoughts are likely to stray unless corraled. The following corrals are, therefore, provided along the way:

(*a*) Units of size.
(*b*) Basis of selection of the unit.
(*c*) Means of Measurement.
(*d*) Typical confusions.
(*e*) Ratings in relation to heat dissipation.
(*f*) Size in relation to the service application.
(*g*) Efficiencies.
(*h*) Insulation.
(*i*) Suggested program for progress.
(*j*) Guidance.
(*k*) Step by step.

Units of Size.

In order to deal intelligently, equitably and conveniently in any article of commerce, it is necessary to refer to some fixed unit of size. The unit may be, and usually is, an arbitrary one selected on the basis of its convenience. The essential thing is that it means the same thing, at all times, and to all parties involved. The con-

sumer is thus enabled to estimate his requirements, to advertise them, and to examine the offerings of competitive bidders in a manner equitable to all concerned.

Everyone is so familiar with the common standards of weight and measure, and so convinced of their worth in everyday life, that they are accepted as elementary facts. When we come to the matter of electrical machinery ratings (*size*), we see the necessity for uniform standards, we assume that the conditions are similar in the non-electrical and the electrical fields, and conclude that the solution is the same in both cases. It decidedly is not.

The differences in the two instances do not mean that there is any more mystery attached to the subject of electrical size ratings than to standards of weight and measure. Nor is it a subject only for experts, medicine men, and witch doctors. All that is required is to start out and to hold on with the questioning attitude of a child, as the following will serve to illustrate.

The standards of weight and measure are material objects, carefully preserved in a national depository, and vary not with time, temperature or humidity. In the words of Pop-eye they are simply "I yam what I yam, because I yam." As yardsticks, they represent a totalitarian, an authoritarian system; a measure of the state of being; and do not represent a standard of performance because they do not perform. This distinction is important.

The standards of electrical (size) ratings, on the other hand, exist only in definitions. They are functions. They do not, and by their very nature cannot, exist as physical objects to be preserved in a public depository. They are standards of performance solely, and not of mass dimensions or other physical attributes of size. They measure not how big the machinery or article is, but rather how big the work is that it can do. Just how "big" that amount of work is, depends upon many factors, among them being temperature.

Certain of these factors have been carefully defined, while others have not. Even where the definition is careful, the so-called standard may become variable, even misleading, if the definition is not absolutely clear, thoroughly understood by everyone, accurately determinable, and exactly adhered to. If we let up on thinking, and lose sight of the ball, the rating (size) of electrical machinery

is likely to end up as a gauge of the effectiveness of advertising, sales effort, or prestige, rather than as a measure of motor effort or performance (horsepower). No man can talk a pound out of being a pound, but, where the full-load horsepower rating of a motor exists only in a definition, it is comparatively easy to produce confusion. "I yam, what I yam, *because I say* I yam." This distinction between the two types of standards (weight and measure—electrical performance) is another important one.

Just to show that the author is not wholly fanatic, a recognized authority will be quoted. In an address entitled "Engineering and Industrial Standardization," delivered in 1919 by Dr. Comfort A. Adams before the midwinter convention of the American Institute of Electrical Engineers (of which Dr. Adams is a past president), he had the following to say:

"An illustration from the electrical field has to do with the rating of electrical machinery. In the early days there was no agreement as to what was meant, e. g., by a ten-horsepower motor. As a result, fair competition was impossible. The ratings of the several manufacturers varied as much as 30 per cent and the customer was at the mercy of the persuasive talents of the salesman. It took the Standards Committee of the A. I. E. E. five years to revise its old system of rating of electrical machinery in such a way as to be rational, scientific, satisfactory to all concerned, and capable of reasonably accurate checking by commercial tests. The results of this work have proved to be of world-wide value. They have placed competition on a far more equitable and generally satisfactory basis; they have encouraged more careful and thorough designing; they have encouraged a more careful selection of size on the part of the user, and have generally resulted in better machines."

Dr. Adams' speech, made 20 years ago, is probably more applicable today than it was then. Due to the economic depression since that date, during which progress in machinery design has not kept pace with the development of new materials and processes, the author believes the way is now open for progress which, compared to the possibilities existent in 1919, is positively astounding. Carrying on with that idea, let us examine the basis of selection of a rating (size) unit, and its means of measurement.

Basis of Selection of the Unit.

There are several limiting factors in the rating of electrical machinery. Most of these are not, however, equally applicable to the various types of machinery. There is just one factor which applies to all types of electrical machinery which, therefore, has now become universally accepted as the *basis* for rating. That factor concerns the maximum *safe operating temperature* of the *insulating material* used in the construction of the machine. Electrical insulation is, at its best, a weak material, and heat serves to weaken it further. The strength (size) of the chain is only that of the weakest link.

In 1913, C. P. Steinmetz and B. C. Lamme published some curves showing the estimated relation between the life of insulation and the temperature to which it is subjected. These curves have been accepted internationally as a basis for rating, and, although they are quite old, the latest researches in the field of insulation tend to confirm the original estimate of the situation. Some points picked off these curves will show that a comparatively slight variation in temperature has a large effect upon resultant life:

Class A Insulation.		*Class B Insulation.*	
100 degrees C.	10 years life	145 degrees C.	10 years life
105 degrees C.	5 " "	157 degrees C.	5 " "
108 degrees C.	2½ " "	162 degrees C.	2½ " "
113 degrees C.	1 " "	177 degrees C.	1 " "
125 degrees C.	⅓ " "	200 degrees C.	⅓ " "
150 degrees C.	0 " "	250 degrees C.	0 " "

It will be observed from the column headed " Class B Insulation " that 145 degrees C. was considered at one time as compared to 100 degrees C. for " Class A Insulation." Later the figures were reduced to 125 degrees C. for Class B insulation and raised to 105 degrees C. for Class A Insulation. These new limits became standards, although there were some who believed them to be too conservative. There were others who advocated even more conservative limits. In order to arrive at some uniform basis, it was necessary to effect a compromise which everyone could subscribe to. Like all compromises, it is likely that it suits no one exactly. The vital thing to remember, however, is that a small difference in the

cause is magnified in the effect; and what seems to be a hair-splitting distinction to begin with, amounts to a respectable difference in the final result. Since the final result is the real criterion, it is meritorious rather than belittling to require the greatest possible exactness in defining and in adhering to definitions of rating with respect to temperature. When one departs even slightly from this position, he should do so with his eyes fully open.

Let us assume that the limits of 105 degrees C. for Class A and 125 degrees C. for Class B insulation represent a 10-year life. Then substracting the ambient (room) temperature from the limits enumerated above leaves the following maximum temperature rises which can be permitted:

(*a*) For an ambient of 50 degrees C.:
55 degrees for Class A insulation.
75 degrees for Class B insulation.
(*b*) For an ambient of 40 degrees C.:
65 degrees C. for Class A insulation.
85 degrees C. for Class B insulation.

It must be clearly understood that the above rises are calculated ones, i. e., they are not, in general, capable of observation. They represent the maximum permissible "hottest spot" temperatures. A "spot" or portion of a machine gets "hottest" because it is relatively inaccessible, thermally, from the outside. For the same reason, it is usually inaccessible for purposes of actual observation. That being the case, we have to admit right from the beginning that usually it is impracticable for us actually to measure the temperature of the spots in which we are most vitally interested. Those "hottest spots" represent the danger points, the weakest links in the whole chain; and it matters not how cool the rest of the machine if these spots are too hot, and consequently weaker than we had been led to expect.

The logical basis of rating is that weakest link, but we cannot measure that link directly. We can only measure the imprint of that link on the next adjacent link. Much depends upon the kind of deduction we make from an examination of that imprint. That is why an 8-HP motor may be talked into representing a 10-HP "size"; although you cannot do that to an inch or to a pound.

That is why it is essential to recognize the distinction between standards of weights and measures, which are unchanging physical objects, and standards of electrical rating, which exist only as definitions; where a slight change in the definition produces a big change in the size of the machine or of its performance. It behooves the purchaser to consider bids from the standpoint of the weakest link in the chain (which actually is an indication of its strength), rather than to judge solely from the nominal chain size.

MEANS OF MEASUREMENT.

There are three recognized methods of measuring the temperatures and temperature rises, viz:

(*a*) Thermometer.
(*b*) Resistance.
(*c*) Embedded-detector.

These methods are fully described in current engineering standards. The essential thing to be noted is that, in general, no claim is made that any of these can be depended upon to measure the "hottest spot" temperatures. Some methods come closer to it than others and for these you employ a smaller "conventional allowance" (correction factor) than for the others. The conventional allowances for the three methods are as follows:

(*a*) Thermometer, 15 degrees C.
(*b*) Resistance, 10 degrees C.
(*c*) Embedded-detector, 10 degrees C.-5 degrees C.

The foregoing does not mean that the thermometer placed on an accessible spot will always read 15 degrees lower than is the actual temperature of the inaccessible hot spot. There are too many unknown factors which may affect this relationship to permit of any certainty on this score. The only thing you do know definitely is that the reading you have taken does *not* represent the actual condition in that hot spot and that you must make some *corrections* to that reading if you are to convert it into terms of the hot-spot temperature. To permit anyone to assign, at will, his own conversion factor, would result in chaos in the rating of electrical machinery. It was necessary for everyone to agree upon

some one conversion factor if any degree of uniformity in ratings was to be assured. That correction of 15 degrees for thermometer measurements represents a careful estimate, based upon average conditions, which has been agreed to nationally and internationally. The same thing may be said with respect to the correction factors assigned to the resistance and to the embedded detector methods.

Subtracting these conventional allowances from the maximum permissible calculated temperature rises, we obtain maximum permissible *observable* temperature rises as follows:

(*a*) For an ambient of 50 degrees C.:

Class A insulation:

40 degrees C. by thermometer.
45 degrees C. by resistance.
45 degrees-50 degrees C. by embedded-detector.

Class B insulation:

60 degrees C. by thermometer.
65 degrees C. by resistance.
65 degrees-70 degrees C. by embedded-detector.

(*b*) For an ambient of 40 degrees C.:

Class A insulation:

50 degrees C. by thermometer.
55 degrees C. by resistance.
55 degrees-60 degrees C. by embedded-detector.

Class B insulation:

70 degrees C. by thermometer.
75 degrees C. by resistance.
75 degrees-80 degrees C. by embedded-detector.

Thus we arrive at the "observable" rises shown in the specifications. The thing to be borne in mind, however, with respect to all observable temperature rises and all methods of temperature measurement, is that, although the fundamental consideration upon which machinery ratings are based is the "hottest spot" temperature, we are not measuring it and cannot reliably measure it. We are measuring something else. This happens to be all we can do about it at present, and it calls for no further apologies. It does, however, point a warning; a warning to hold tight, lest we become confused.

Typical Confusions.

There is much danger of one's losing the road at this point, by taking the wrong fork. We have measured something, but we are not sure just what it is. We may get confused and mistake the nearest substitute for the real thing. An example or two will serve to make this clear.

Consider two machines, both Class A insulated, each with their rating based on a 50-degree C. ambient. Assume that the shunt field temperature rise is 40 degrees C. by thermometer in both cases. We might conclude that the two are identical as to "size" because they measure the same by this method. But assume that upon further investigation we find the temperature rise, as measured by resistance, is 45 degrees C. for machine No. 1 and 55 degrees C. for machine No. 2. It is clear that we were not on safe ground when we judged them to be equal in "size" (performance).

In general the thermometer reading represents the temperature of the *exterior portion* of the coil, whereas the resistance method indicates the *average interior*. If the exterior is the same in both cases but the average interior temperature of machine No. 2 is considerably greater than that of machine No. 1, it is obvious that the maximum interior temperature of machine No. 2 is likewise considerably greater than that of machine No. 1. Since machine No. 1 was rated as high as the specifications permit, then machine No. 2 was overrated.

Take another case: Assume two coils of exactly the same design except that one be treated in such manner as to increase its thermal conductivity, whereas the other is left untreated. Pass such current through each that the wattage losses are exactly equal in the two cases. Place thermometers in exactly similar positions on the exterior of the two coils. Supply enough additional ventilation to the untreated coil to cause its thermometer to read exactly the same as for the treated coil. Then take the temperature of both coils by the resistance method. It will be found that the average temperature of the untreated coil is much higher than that of the treated coil. Then the differences in the "hot spots," which are the *basis* of rating, will be greater yet. So what is their "size"?

There are several other examples which might be cited. It is believed, however, that the foregoing is sufficient to show that

unless one keeps the primary basis of rating in sight at all times one is apt to get side-tracked. We started out to rate machinery on the basis of the "hottest spot" temperatures, but unless we are very careful, we are likely to wind up by *comparing them on the basis of their cooler spot temperatures.* The cooler spot temperatures are only of value if we know about how much to add to make them representative of hot spot temperatures. The use of the cooler spot temperatures is predicated upon a certain relationship to the hottest spot temperatures. When that relationship is destroyed, or not made use of, the basis for uniformity in rating is destroyed.

Ratings in Relation to Heat Dissipation.

The problem of machinery rating is, in so far as temperature is concerned, essentially a problem of heat dissipation. Experts have already suggested that rating in terms of horsepower or kilowatts tends too much toward confusion, and that a much clearer view would be obtained if the machine were rated as though it were an electric heater. Its useful output is dependent upon its ability to dissipate heat. The lower the resistance it offers to the transfer of heat from the innermost parts to the outside, the greater its efficiency as a heater. The greater its efficiency as a heater the greater the load which can be applied to it safely. To rate it in horsepower or kilowatts is to make the unit of machinery size a function of its application. That function is a variable. You lose no time at all in getting thoroughly confused if you follow that line.

If you think in terms of electrical circuit efficiency, however, you immediately seek a means of reducing the losses concerned with the flow of electricity along a conductor. You know that you could apply a higher voltage and thus force a greater current to flow, but you then would increase rather than decrease your losses. The only way you can decrease your losses is to *decrease* the *resistance* to the flow of electricity. In short, you should increase your electrical conductivity. The same reasoning applies to the magnetic circuits; you seek increased permeability. Then why not apply this reasoning to the thermal circuit?

Just so long as you tie up machinery ratings with their applications, you forget the thing you started out to do. If you will con-

sider an electrical machine as an electric heater and apply the same reasoning to it as is outlined above for electric and for magnetic circuits, the problem is clearer. Increasing the efficiency does not call for increasing the force by which that heat is dissipated. What is really needed is to *improve the thermal path* so that the *heat can get out* more easily.

When the problem is considered from this standpoint, it opens up an entirely new view of the matter. There is an internal source of heat, and it is vital that the material in contact with that source be not exposed to too high a temperature. As electrical insulation is, in general, pretty good thermal insulation, you have that source of heat more or less bottled up. Let us examine different degrees of bottling; for example, take two sources of heat and completely enclose them in jackets of similar size, thickness, etc., but of different materials. Let us make one jacket of copper which is the best thermal conductor available and let us make the other jacket of the best available thermal insulation. Let us assume further that it is very important that we know, within a few degrees, the temperature of the heat source, but that we cannot measure it directly. Let us place a thermometer on the outside of each jacket and measure the temperature. Suppose the two thermometers read exactly alike. Do we suppose for an instant that the sources of heat are also at the same temperature? Suppose, again, that the two thermometers do not read alike and that a fan is directed against the hotter jacket until both thermometers do read the same. Do we conclude then that both sources of heat have thus been brought to the same temperature?

The foregoing illustration is purposely exaggerated to make the issue clearer. The difference is in degree only. That difference may amount to as much as 30 per cent, however, in the rating of two machines. It is not a hair splitting distinction by any means. It shows the importance of using every available means of determining temperature if there is to be any such thing as a uniform standard of rating. It discloses the danger of placing too much reliance in certain assumptions such as "conventional allowances"; while they have their place, care should be taken to keep them in it, and not let them confuse us.

Size in Relation to the Service Application.

Summing up these several illustrations, it should be pointed out that in so far as the application is concerned it makes no difference what the unit of rating is. One would use just as much coal, for instance, whether a ton was 2000 pounds or 2240 pounds. It would take just as much lumber to build a house, and no more, whether the units of linear measurement were doubled, quartered or left as they are. The only proper function of size or rating standards is to assure a definite and uniform unit of size. The question of how many units of that size are required for a given application should rest with the specifications for that application. That is the only way in which you can preserve any standard unit.

Let us examine the effect of a change in rating upon the weight and cost of the electrical machinery for a given application. That application doesn't care whether we call a motor 8 HP or 10 HP, for it is only concerned with the actual power required. Suppose, however, we assume the power required to be 10 HP and order on that basis. Suppose further that two manufacturers bid upon this job and that the 10-HP motor of one manufacturer is considerably heavier and more expensive than the 10-HP motor of the other manufacturer. Suppose we try the smaller motor and find it perfectly satisfactory for the application. Are we justified then in assuming that if we insist upon that *unit* of rating typified by the larger motor, we must accept an increase in weight and cost?

Before we answer this, let us first find out if the larger motor is underrated. In view of competition, this is unlikely. It is far more likely that the smaller motor was overrated and that the application never did require 10 HP. It probably required only 8 HP. If we had called for only 8 HP in the first place and insisted on a uniform basis of rating, the first manufacturer would have had to rerate his motor (previously 10 HP) to 8 HP and the second manufacturer could offer his standard 8-HP motor in competition with it. It may be, now, that the second manufacturer offers the lightest and cheapest motor, but even if the first manufacturer's motor is still in the lead there has been some real competition where none existed previously, and this should be reflected in the price. At any rate, we do no worse than accept the same

motor, now rated 8 HP, that was formerly rated 10 HP. That does not look like increased weight. No actual facts have been changed; we have merely come nearer to the facts themselves by dissipating some of the confusion which separated us.

One can not save weight by calling something larger than it actually is and then using a large factor of safety to cover it. It is better to know more closely what it is and then apply a smaller factor of safety. One can save weight by more exact knowledge and smaller safety factors. One does not have exact knowledge when one does not know what "10 HP" means.

Efficiencies.

These illustrations cover but a few of the vagaries encountered in the problem of electrical machinery ratings. While they directly emphasize the matter of heating, there are many other more or less indirect features which are reflected therein. For example, take the apparently simple matter of rated "efficiency" in a motor. Simple, in principle, because it is merely the relationship between "output" and "input."

In actuality, however, the simplicity disappears when we put it into practice. Partly through mental laziness, partly through a desire to avoid testing expense, and partly through disagreement as to test methods and procedure, we arrive at a "negotiated" efficiency rather than an "actual" or "true" efficiency, which could be obtained only by fighting the thing clear through. We sit down around the council table and "agree" on certain assumptions. Then we take these "assumed" values and add them up; after some calculations, we arrive at a "conventional" efficiency.

The error creeps in because we assume that the input minus the assumed losses equals the actual output. This may amount to as much as a 10 per cent difference in the actual or "true" efficiency. Since the "conventional" efficiency is always higher than the "true" efficiency, we may be fooling ourselves to the extent of that difference, i. e., the motor is not as "big" as we thought it was, because we are crediting it with doing more than it is actually doing. It is too rosy a picture.

The manner in which comment from Industry has been reflected in changes in the Navy specifications is of interest in this connec-

tion. One of the early drafts of a Navy specification defined both the "conventional" and the "directly measured" efficiency, but did not clearly state when one was to be used and when the other. So there began a process of attrition. After some criticism, and much discussion, 200 HP was settled upon as the limit above which the "conventional" method was to be permitted, and below which the "directly measured" was to apply. Later, after more discussions, this value was whittled down to 100 KVA and then 25 KVA. Finally it was omitted altogether, with the result that this "negotiated" or "conventional" efficiency is now permissible in all cases.

It is easy for one to say, "Well, why did not the Navy hold its ground?" The answer is not, however, as simple as it may sound. It is difficult to fight many different battles on several widely different fronts at one and the same time. There were lots of other battles going on. Furthermore, if one should contend that "everybody is out of line but Johnny," then Johnny soon gets into step, too. It is practically inevitable.

Insulation.

Electrical insulation is a fit subject for a book (or several of them), not just a few paragraphs. But even a few paragraphs will serve to illustrate the point that we are faced with too many assumptions here also. We "assume" this or that, and others agree. They "assume" this or that, and, in the absence of enough good ammunition to the contrary, we hold our own fire. Knowing that we are so weak, in a field so big, we fear to take a strong stand lest we be mistaken. Again we "negotiate." All, all is negotiation.

According to politicians, any plan, even an incomplete one, beats no plan. Thus the first general plan, inaugurated over 25 years ago, based upon the estimates of Kennelly, Steinmetz, Lamme, Adams and others, and providing for the division of electrical insulation into 3 main classifications, labelled A, B and C, respectively, was so much more of a plan than anything which preceded it that it beat everything else at that time. Had not such tremendous strides been made in chemistry and in accumulated knowledge since that time, the plan would still be the only one in sight.

As matters now stand, however, there are a number of weak spots in that plan. For example, almost everyone now knows that the term " organic " covers a lot of territory in the material world. To lump all the " organics " under a single Class A and to say in effect that these can all be considered equal as to heat resistance and aging, is to give official credence to something we all know is simply not true. Some are very much better than others; yet the rules make no distinctions whatever between them. It is almost as if one lumped all white men in the same category as to weight or ability or longevity. Calculations based on such broad assumptions do not convey an adequate idea as to size or importance or anything else very definite. The same is true of materials. Twenty-five years ago we accepted without hesitation some things we now question. In short, we have learned to wonder if we know. The author supects that this little gap in our knowledge may make as much as 25 per cent (or even 35 per cent) difference in the rating of electrical machinery. He wonders, if we, even yet, really " know our sizes."

The above refers only to the variations among different organic materials in the same class (Class A). There is still a larger error in assuming that even the same material has the same temperature or aging limitations under different conditions. Just as a man has a different weight, mental ability and life expectancy when serene than during or following torture, so has a material. Take a simple piece of rubber, for example: it does not have just one life expectancy or temperature limit, it has many. In fact, its numerous lives are worse than the familiar example of a cat; when one stops to ponder them, he takes on a new respect for the general theory of " relativity."

The immensity of the field of " organics " as a whole, is such that one's vision is apt to be blurred unless he can narrow the field down to some one spot; as one does with a high-powered field glass or a microscope. For the moment, do not even try to focus on rubber, as such; there are too many thousands of different rubber compositions, some members of that family being more widely different from other members of the same family than they are from the nearer members of a distant family. Just focus on one very specific rubber composition, such as the " Navy 40 per cent "

rubber used for the last 20 odd years on Navy cables under Specification 15C1. This is exceedingly narrow ground, almost a "spot." The Navy should have become acquainted with it after all these years, but hasn't. It "does the strangest things."

What a difference circumstances do make, how they do alter cases, in a simple thing like that "40 per cent" rubber. Freed from external physical stress and bottled up in a lead sheath so that air and moisture can not get to it, the rubber lives to a ripe old age, even at temperatures far beyond those usually associated with it. The *serenity* of its existence and relative freedom from oxidation worries explain its *longevity*.

The same rubber composition, "reinforced" by fabric and then enclosed in a basket-weave metal armor which is itself so heavily encrusted with repeated applications of paint as to keep out air and moisture, also gives it old-age insurance. If the author but dared to do so, he might name a temperature limit under such protected conditions that would utterly shock you. No one would believe that rubber could be so good. Serenity does it.

Again, with the same rubber composition, but with the fibrous reinforcement omitted and the outer protective barrier to air and moisture gone, you will have to knock off 20 degrees C. to 30 degrees C. from the previous temperature limit if you would retain any comparable longevity. Go further and insist on your right to "wiggle" it from time to time, and you will have to knock off another 10 degrees C.-20 degrees C., "or else." Go still further and bend it sharply in a fixed position so as to give it a stiff back, as it were; then its life is a matter of weeks or months, no matter what the temperature is. And if you really want to worry it and shorten its life, no matter how light the temperature or load, then give it a sun-bath while it is bent over sharply, in a fixed position. In such a fix, it cracks under the strain in a matter of hours, not months nor years. Now, what is the *temperature limit* and what is the life of rubber? The author is not trying to tell you, he is asking.

Rubber was chosen for the above illustrations because everyone is familiar with tires, garden hose, rubber bands, etc. It is simple, down-to-earth stuff that everyone can understand. The ideas, however, are applicable to the whole field of organics, and not just

to one little patch (rubber) in that field. And the author purposely kept it simple; one specific application (cable), of one specific composition (40 per cent), of one specific class (rubber), of one general (organic) group. That is certainly narrowing the field. When one covers the whole field of "organics" in one sweep, however, and says that its temperature limit is 105 degrees C., or 60 degrees C., or anything else, he is certainly covering a lot of ground. One again asks, do we really "know our sizes"?

Program for Progress.

As stated earlier herein, the author's attitude in this matter is one of questioning, not of "telling." If the approach to some of these questions appears too emphatic, the idea is merely to compel attention in a subject usually thought of as just too dry for words. It is admittedly agitation, of a sort, but distinctly not intended as demagoguery. The thought is to build upon, not tear down. In order, however, to attain this end, it is first necessary to sell the idea that the whole scheme of electrical machinery and equipment ratings, as based upon the temperature limitations of electrical insulation, should be opened up, modernized, streamlined.

Furthermore, *there is a definite program for doing something about it.* But that program is not a hard and fast or arbitrary one; it is a tentative, directional, functional, feeling-out-the-way sort of program. One might almost term it a *definite scheme for muddling through.* There are several phases to it; no one phase is all-important. There is no single thing which is the solution of any real problem.

Solutions (and that is what progress is, fundamentally) lie mostly in the combining of a lot of little answers rather than in the chance discovery of some one big thing alone. Mostly, progress is just a matter of brick-on-brick, stone-on-stone stuff. The most important thing about any "phase" of a problem is the matter of "phase sequence." The foundation is neither more nor less important than the roof, but, ah! the "sequence," the foundation should be laid first.

It is believed that the first step in that program is one of enlivenment and encouragement; and that has been the aim of this first in a series of discussions on this subject. Certainly the electrical

art is a living, growing, outwardly expanding force; so the "yardstick" by which its progress is measured can not be wholly dry and uninteresting. The term "dynamic" very aptly describes that force; and if we are not now talking about how "big" is a "dynamo," the author certainly did get off to a bad start. To further enliven such a dynamic subject, it might be in order to mention certain "war aims" of the Navy. Briefly these are to secure "twice as many horsepower in the same space, and at ⅔ the present cost per horsepower."

As a second step, a little debunking might be in order. While the author hesitates to offer anything along that line, it might be desirable if some better-qualified critic did do something of that sort. Rating is not in the class of sacred cows, in spite of the eminence of the authors of the present rating scheme; for, after all, 25 years is a long time for a dynamic subject to remain static. Nor do those 25 years of being stored in the attic prove that anything is haunted. In fact, the only mystery involved is the fact that there are some questions we do not know how to answer. If we do set about chasing some of these spooks, we may be able to generate some dynamics in ourselves. That would help some, even if, like the author, one must start out whistling.

Diagnosis might well be the third step in such a program. One must first study the ailments before attempting to prescribe remedies. The author not only does *not yet* presume to know the answers; he is even afraid that he would not recognize them if someone else did point them out. How does one tell quickly, i.e., within a few weeks or months, which is the right answer and which is the phony one 10 years from now? For Naval installations, the conclusion at which one must jump may be 15 years or 20 years ahead. The author emphatically does not know the answers, but he does know some questions; not expertly, nor academically, but with intimacy and abandon. He cherishes the opportunity, in the next article of this series, to lay a few of them on the line. This first article is merely by way of reconnaissance.

Step four calls for better "yardsticks," i. e., more accurate methods of testing, and *fewer assumptions*. In short, we want to *test the motor* and *not the tester*. As the mystery clears away and we *find out* instead of *deducing*, some of the Sherlock Holmes

technique may be abandoned. How could we tell when we had a twice-as-big motor at the wind-up of our program if we do not know how big it was to start with? This is a most difficult step, and a long-time proposition, but some well-placed questions might point the way. Certainly, the questions will interpose no barriers to progress, even if they lick us.

The fifth and last step (and, incidentally, every other step) must of necessity be one of *cooperation*. The reasons for this are plain, so plain that they might be overlooked unless we are careful to keep them in mind always. So as to remember not to forget, let us make a memorandum to that effect; and refer to it as a guiding procedure, or simply "guidance."

GUIDANCE.

The Navy is not prepared and is functionally unfitted to manufacture all its own electrical machinery and equipment; it must obtain the greater part of it by open purchase in a competitive market, under specifications fair to all concerned. It may not dictate design, but it can do some guiding of manufacturers along the technical lanes which seem most appropriate in meeting the severity of Naval shipboard conditions. In short, the program is founded on the proposition that the Navy cannot go it alone; any effective technical progress which it can hope to accomplish must be done in concert with the electrical industry of this country.

The subject of "big" little motors is one of such inherent possibilities, and so in keeping with present Naval engineering trends in weight reduction, that one must be guided by caution in its every approach. Approached with blinding enthusiasm, and without circumspection, it might become a fit field for fanatics, and thus backfire. To guard against that contingency, the following guiding principles are offered as a general line of march in the assault on the problem.

The program presupposes that many weaknesses and disadvantages in the use of the newer materials and the newer techniques do exist, and that there is going to be very much more to the job than the mere act of *shaking down* someone else's *full-grown trees and having a lot of ripe, perfect plums fall* into our lap. Rather it

provides an opportunity to plant and to hybridize and to cultivate and to spray, according to the best information which is now available, or as it may become available through research.

It also assumes that there is to be neither driver nor driven, as between the Navy and Industry, but rather that there shall be leading; and that this leading shall be of such a high order as to create a desire to cooperate, and to keep on cooperating. To accomplish this, the program must be one of absolute fairness to all concerned; so fair that none can hope either to gain by monopoly or to lose thereby insofar as any act of government is concerned. Cooperation can take place only on such a high plane. Where joint action takes place on any lower plane, it leads to connivance, and connivance merely divides up something already built; it never builds.

Since this program must, to succeed, be one of building-up, it stands to reason that a line of demarcation must be clearly drawn between "cooperation" and "connivance." One goes up, the other down. Direction is important.

Cooperation does not just happen; it has to be planned for. To be effective, it must be planned and executed under a unified command or direction having the confidence and respect of all parties concerned. The exercise of that unity of direction, to be effective, necessitates that the one who does the directing must know as much (or more) of the weaknesses of each of the products as its manufacturer himself knows; otherwise he is just as helpless to proceed effectively as would be a lawyer who did not know his client's case.

But that knowledge, so essential to effective direction, carries with it certain obligations; an obligation to use it to general advantage and not to the disadvantage of its source; an obligation not to take from one and give to another, to see all and hear all, but not to tell all, particularly that which gives an undue advantage or imposes an unnecessary disadvantage to someone. Unless one is always conscious of these obligations, he will be unable to tap the several essential sources of information or to maintain those sources of information. When confidences are abused, the sources dry up; the Navy's contacts with Industry are destroyed.

There is, however, a nucleus of faith in the Navy's fairness; and the Navy can employ that confidence just so long as it is

merited, and so long as it is employed for the sole purpose of meeting Naval needs. In proposing such use, it is strongly urged that this present nucleus be built upon, and that every effort be made to provide against its possible abuse. Since it is so easy to abuse a good thing, and since that abuse is far more likely to come about unintentionally than otherwise, it may be helpful to invite attention to the manner in which this might happen. It is easy to kill the goose instead of waiting for the golden eggs.

One of the fruits of asking questions, of testing the product of the numerous individual manufacturers, and of the technical discussions which follow, is the improvement of old ideas and the birth of new ones. This is as it should be, but it brings up the question of parenthood; whose child is it? This is a simple question; much simpler than any possible answer which would be fair to all. And this is the rock on which further cooperation is smashed if the answer is not the right one. So the fruits, even of cooperation, are not going to amount to much unless this elemental fact is squarely faced.

The foregoing is merely by way of saying that at least half of this problem, and much more than half of the risk, involves the development of confidence and respect; the harnessing of many minds for working together rather than in opposition, which is the more common tendency. If that can be done, if the common tendency can be reversed, the technical problems should be easy to solve. The solution of the technical problems can be achieved through a cautious brick-on-brick, stone-on-stone, step-by-step approach.

Step by Step.

The following plan of procedure is submitted with the foregoing in mind. While many details are covered by the plan, these may be shifted as the program proceeds and as we learn more. What we think important today, as a detail, may not work out, and so tomorrow we may drop it. If we were sure, now, there would be no use of experimenting. So the details are shown merely to illustrate the basic ideas, to give them point. The *direction,* the *trend,* is the important consideration; and it is to be emphasized that this features as its cardinal virtues:

(*a*) A *questioning* frame of mind.
(*b*) The maintenance of *confidence* in the Navy's fairness.
(*c*) An *experimental* approach.
(*d*) A massed or *cooperative* attack.

STEP NO. 1.

The first step is essentially an *estimate of the situation,* a survey of the service needs and of the existing possible means of meeting them. Actually, this has been in progress for something over 10 years, during which time many hundreds of tests have been made and considerable data are available for analysis. In order, however, to establish some "bench-marks" from which to make the start, it is necessary to prepare a number of proposed Navy Department Specifications. The "questions" which have been uncovered in this estimate of the situation are largely responsible for this series of articles and for the program in mind. This estimate is constantly under revision.

STEP NO. 2.

This step consists in making available to industry, through the medium of Navy Department purchase specifications, the technical data gleaned from Step No. 1. About a dozen new specifications are involved, covering several of the newer types and classes of electrical insulations. Some of these specifications are now in the course of preparation; the others to follow as soon as practicable. It is to be emphasized that these specifications will not attempt to state what an insulating material is to be made of, nor how it is to be constructed; but rather what its performance must be, i. e., the specifications will define *functions* rather than constructions. These specifications, serving as *bases* and *definitions,* will be utilized in Step No. 4 for the further development of electrical insulating materials and combinations of material; and again, in Step No. 6 for the purchase of new, lightweight designs of electrical machinery.

STEP NO. 3.

Expedite the completion of the several projects covered by experimental directives having to do with development of better testing methods. This phase already has been in progress for about two

years, and much of it is nearing completion. Accelerate the tempo. Add new objectives as fast as these can be foreseen. The new test methods, the new " yardsticks " upon which the most emphasis is being placed at present (and for the immediate future) are longevity, heat resistance, stability, permanence, flame resistance, arc resistance, oil resistance, acid and alkali resistance, sea water resistance, abrasion resistance, deep drying, moisture resistance, thermal conductivity, impact resistance, plastic deformation (yield or " creep "), dielectric strength, insulation resistance, power factor, dielectric losses, etc. While some of these methods have been utilized before, they were primarily adapted to the use of the older materials; and the development of the newer materials and newer techniques (glass fibre, films, synthetics, etc.) requires a different approach. The newer test methods are to be streamlined along functional lines so as to provide for what is to be rather than for what has been.

STEP NO. 4.

This is where industry " cooperation " must begin to take hold in a thorough manner. Prepare inquiries for submission to several manufacturers of electrical insulation, asking them if they desire to quote on certain new developments in electrical insulation. Purchase and test these under the usual development procedure. Several possible new combinations and improvements now suggest themselves. Others will no doubt come about as the experimental tests proceed.

STEP NO. 5.

This will include the preparation of inquiries for submission to a number of the leading manufacturers of magnet wire, for use in the coil windings of electrical machinery. Such inquiries will be based upon the specifications prepared under Step No. 2, with such modifications and improvements as may seem desirable and practicable. Otherwise, proceed as in Step No. 4 and immediately following Step No. 4.

STEP NO. 6.

Prepare inquiries for submission to several (at least 5) manufacturers of electrical machinery, asking them if they desire to

quote on certain new lightweight designs of electrical machinery. It seems advisable, at present, to try out some of these new ideas on 10-HP motors, these being about the smallest and least expensive size for getting data applicable to larger motors and generators. The thought would be to procure and test one 10-HP motor from each of 5 manufacturers, representing the present stage of the art. Then, utilizing all the data obtained by tests and developments (Steps Nos. 1 to 5, inclusive), specify experimental motors of such design as to obtain, say, 20 HP from the present 10-HP frame size. The present objective is to double the motor capacity by taking advantage of the possible gains in each of about 5 different directions which now suggest themselves.

Further Steps.

It is not to be assumed that our final objectives will have been reached by the time Step No. 6 has been concluded; but we should know by this time if the road we are following still leads on; we should know how far we have come and at what cost; and we should be able to see so much further into the future than we can at this time, that it would be foolish to attempt now to say just what the next step should be. Most assuredly we will find certain weaknesses that we know not of at present, but, if we can save one-half the present weight and one-third the present cost of the tonnage of electrical equipment aboard ship, costing millions of dollars, a few thousand dollars in cooperative experimentation to gain that end looks very much like a bargain.

Summary.

Much progress has been made within the past 20 years in the production of improved forms of electrical insulation. Not as much has been done in its actual utilization. What are some of the problems here, and what might be some of the fruits of experimentation? The answers to some of the questions could be very *useful*. How is the best way to ask questions and how do you know if *an* answer is *the answer?* Much depends upon *how* the questions are asked. This is one approach, one *how*. Do we hear another?

APPLICATION OF CONTROLLED DIRECTIONAL SOLIDIFICATION TO LARGE STEEL CASTINGS.

By Joseph A. Duma * and Stanley W. Brinson.†

Large steel castings, particularly those of intricate shape, are nearly always associated with the presence of internal flaws. Necessity for improvement in foundry practice becomes apparent after a study of the present-day uses of highly stressed castings for structures and for pressure vessels. The methods of improvement fall naturally under three heads. First, the improvement of foundry technique in order to reduce the number of flaws which lie below the standards of acceptability. Second, the development of radiographic inspection as a part of production control in order to discover harmful defects. Third, the extension of repair by welding to all harmful defects in order to insure the integrity of the casting and to prevent its costly rejection.

An article, "Steel Casting Design for the Engineer and Foundrymen," by C. W. Briggs, A. R. Gezelius and A. R. Donaldson was published in the May, 1938, issue of the Journal. *The article derived from an intensive study by the Naval Research Laboratory of the phenomena of directional solidification. Following the laboratory study, tests were made at the steel foundry in the Norfolk Navy Yard in order to determine the application of the laboratory findings to actual foundry production. Cooperative effort between the laboratory and the navy yard was most successful. Thus, it becomes a great privilege to publish results of the foundry experience in the ensuing article as a sequel to the earlier article on laboratory development.*

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PART I—INTRODUCTION.

The total and partial reversal methods of applying controlled directional solidification to castings are fairly well known to foundrymen. Unfortunately, the reversal systems are not applicable to all manner and size of castings, their range of usefulness being limited to comparatively small and medium size structures. Huge molds containing from 10,000 to 30,000 pounds of liquid steel cannot be craned for reversing with the same facile promptness and safety as molds containing one-tenth that amount of metal. This does not by any means preclude the use of the principle of controlled directional solidification to large castings. Favorable temperature gradients can be imposed upon them, but in a manner distinctly different from that used in the reversal systems. In the following pages actual cases will be presented illustrating the various ways in which the direction of solidification is being successfully controlled on large work. The castings whose manufacture will be described are anchor shanks and anchor crowns, globe valve bodies, main and intermediate struts, turbine casings, throttle valve bodies, and heavy ring sections.

Controlled directional solidification, while admittedly indispensable for the procurement of solidity in castings, per se, is unable to achieve flawlessness. The degree of excellence attained in mold-made structures is further dependent upon their design, the manner of metal handling, and last, but not least, molding technique. Perfectly sound castings are rare. In order, therefore, for a casting to be as nearly perfect as possible, the best effort and the highest skill of the designer, melter, molder, and patternmaker must be incorporated into it.

An eminently successful foundry technique has been evolved at the Norfolk Yard for the founding of large and intricately shaped castings, notably turbine casings. The high degree of success achieved is referable principally to: (1) the foundry's employment of miniature models for a critical study of the proposed design prior to the making of the final patterns; (2) the foundry's insistence on the application, to the fullest extent practically possible, of the principles governing directional solidification; (3) the practice of mechanically relieving molds and cores after pouring; (4) to

the foundry's use of synthetically bonded silica sand mixes in mold construction; (5) to the high quality of its steel; (6) and, lastly, to its constant and widespread use of gamma raying for the examination of the internal structure of all critical sections. Needless to say, the wealth of technical information generously supplied the Yard by the Naval Research Laboratory likewise contributes to the success attained.

Commenting very briefly on each of the foregoing practices, and in the same order, it is stated that a preliminary study of subsize models invariably leads to constructive changes in the original design. Complicated appurtenances which interrupt the symmetry of the main body are either left off, to be cast separately, or they are left intact, depending on whether they interfere with the proper feeding of other sections, and whether they themselves are amenable to feeding. All corners are properly radiused; sharp re-entrant angles are suitably filleted; thin and thick sections are run into each other gradually; sudden dips and sharp changes in the surface contour are straightened out; jointing of other sections is carefully checked over for potential hot spots; and, where possible, the entire transverse section is heavily tapered or padded from the bottom to the feeding heads, thus simulating the big-end-up mold design of the steel mills. The placement of feed heads and the manner of core anchorage are also worked out. The result usually is a design that is castable with the minimum amount of potential defects.

Models are self-paying. Costing approximately 2 per cent of the total founding cost of a casting, they effect savings of equivalent or greater magnitude. By referring to the model, the making of the pattern, core boxes, and mold is greatly expedited. Chipping of exterior padding is also hastened.

Controlled directional solidification, when properly applied, is generally productive of a uniformly solid casting, free from nearly all the shrinkage defects which are wont to afflict the conventionally made product, i. e., micro-pipe, cokey texture, pronounced center-line weakness, gross shrinkage cavities, and internal hot tears. This topic is dealt with at greater length in Sections 2 and 3 of this paper.

Mold relieving is to a casting's solid contraction what directional solidification is to its fluid contraction. Solid contraction is a problem which involves the questions of hot shortness of metal and deformability of molds. The relieving of molds after pouring helps obviate external hot tears. In order for a casting to tear, two conditions are necessary, namely: high temperature (2300 degrees-2550 degrees F.) and high hindered contraction stresses (800-2500 pounds per square inch) (1).* Since, of the two, the latter are controllable, and therefore avoidable, the cure for them is self-evident. To prevent the stresses opposing contraction from building up to magnitudes exceeding the strength of the metal at the above temperatures, mold and core materials must possess, after pouring, immediate and ready collapsibility. Green-sand molds exhibit this behavior to a remarkable degree. Mold resistance is lowered still further by mechanical loosening of cope bars and tie rods, by pulling out and relieving blocks, and by breaking core crabs. Because they permit the casting to contract unobstructedly at both high and low temperatures, all the foregoing operations help save it from failure by hot tearing.

Sand conditions, too, are responsible for a large proportion of defective castings. Some of the more serious casting defects directly chargeable to sand are blows, pinholes, and gas cavities, scabs, buckles, and rough surface, drops, cuttings, and sand inclusions. Synthetically bonded sand mixes—consisting of washed silica, water, and bentonite—are not only simple in composition and inexpensive, but remarkably resistant to damage by molten steel. Ample protection is secured for the solidifying casting against the first three defects by the absence of organic (gas forming) materials in the mixes, low moisture content, and high permeability. A nice balancing of the various physical properties of these mixes—in practice secured by suitable tempering, ramming, and drying—will safeguard the casting against the remaining defects. The composition and physical properties of the various sand mixes used for making each of the castings herein described are contained in Table I of the Appendix.

Melting technique is responsible for two very serious ailments—porosity and low ductility (2). The former is a disease of insuffi-

* Numbers in parenthesis refer to the bibliography.

ciently deoxidized steel, while the latter is associated with over-reduced steel. The Yard manufactures steel in a basic electric furnace, under two slags—the first a product of restricted oxidation of the melt, and the second, consisting of strongly basic and highly reducing materials, the product of several degassification and physicking reactions. Table II, in the Appendix, gives the chemical composition of representative samples of each slag and of the metal they covered. Degassification of the melt is accomplished in the furnace with ferro-silicon, ferro-manganese, and ferro-titanium, and again in the ladle with calcium silicide. The melting down of the bath under a slag whose oxidizing power is sufficient to bring the silicon in the charge to .02 per cent or less, together with the high degree of degassification achieved in the refining period, plus the fairly high percentage of new residual silicon (.25 per cent-.35 per cent) in the metal, result in the production of a metal remarkably low in occluded or dissolved gases. This practice, and the results obtaining from it, are in the main analogous to those discovered by C. McKnight, Jr. (3).

Regarding ductility, examination of tensile tests of annealed steel coupons show the metal to have an average elongation and reduction in area of 30.0 per cent and 50.0 per cent, respectively. More completely, the physical properties of representative heats of the principal steels made are as follows:

N. D. Spec. No.	*Class*	*C.*	*Mn.*	*P.*	*S.*	*Si.*	*Ni.*	*Mo.*
49Sli	B	.25	.59	.02	.02	.36	.21	None
46S33	C-Mo	.25	.67	.02	.01	.28	.21	.40

Class	*Treatment*	*T.S.*	*Y.P.**	*Elong.*	*R.A.*	*Bend*
B	Annealed	70,250 psi	43,000 psi	32.0%	51.5%	180°
C-Mo	Annealed	73,500 psi	45,500 psi	28.5%	46.0%	180°

In the absence of any effort at regulation of residual oxygen in the metal, it is believed that these high values are the result of a very effective degassifying and desulphurizing practice. The calcium carbide present in the second slag desulphurizes the steel to so low a value (.010-.015 per cent) that there are not enough sulphide inclusions left to cause appreciable damage to ductility, even in the presence of a predisposition toward intergranular separation. The

* Dividers.

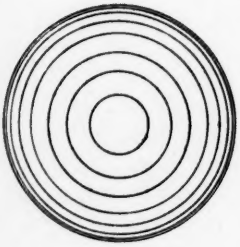

FIGURE 1 — DIAGRAM OF ISOTHERMS IN A CYLINDRICAL CASTING WHILE COOLING.

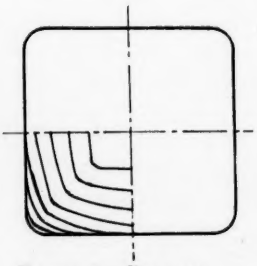

FIGURE 2 — DIAGRAM OF ISOTHERMS IN A QUADRANT OF A SQUARE CASTING WHILE COOLING.

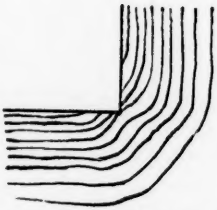

FIGURE 3—DIAGRAM OF ISOTHERMS AT A RE-ENTRANT ANGLE IN A COOLING CASTING.

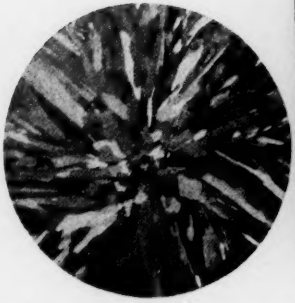

FIGURE 1A — CRYSTALLIZATION OF HOT STEEL IN A CYLINDRICAL MOLD.

FIGURE 2A — CRYSTALLIZATION OF HOT STEEL IN A SQUARE CONTAINER.

FIGURE 3A — CRYSTALLIZATION OF HOT STEEL AT A RE-ENTRANT ANGLE.

NOTE THE NORMAL DISPOSITION OF THE PERIPHERAL DENDRITES.

almost complete elimination of silicon during the meltdown, and its subsequent replacement with new silicon, also helps secure higher ductility.

The sixth and final factor which indirectly assists in the production of sounder castings, as was previously stated, is radiography. Radiographs, when studied in relation with the effect produced by changes in design, molding, and melting technique, not only serve to locate and identify internal ailments, but also are instrumental in suggesting the proper remedy for overcoming them. Needless to add, many of the newer advances made in the art and science of founding have been made possible through radiography.

Part II—The Principle of Directional Solidification.

The principle of controlled directional solidification has been expertly described in an article by the late George Batty in the February, 1934, issue of the Journal of the American Society of Naval Engineers. A more extensive treatment of the laws governing its operation is contained in the May, 1938, issue of the same Journal, under the authorship of C. W. Briggs, R. A. Gezelius and A. R. Donaldson. For those few who are as yet unfamiliar with its modus operandi, we venture the following elementary explanation. The physical laws governing the direction of solidification shall be considered first, and secondly, the genesis of internal unsoundness.

Solidification, or preferably crystallization, always progresses in the direction of the hottest metal, i. e., along the lines of heat flow, the crystal growth taking place in the direction opposite to that of the flow. This process of growth in directions at right angles to the isothermal surfaces, and opposite to the lines of heat flow, governs the crystalline arrangement of all castings. The position and form of the heat isotherms, in turn, is determined by the geometry of the container and the conditions of cooling. The isographs in Figures 1 to 3 illustrate the influence of the shape of the container on the heat isotherms and the consequent crystal arrangement in each.

In the light of the foregoing, witness what happens after molten metal has been poured into a mold. Immediately upon contact of the molten metal with the relatively cold walls of either a sand or

a metallic mold matrix, an initial thin skin solidification occurs. This outside skin, consisting of exceedingly fine chill crystals, fixes the external dimensions of the ingot. Using the chill crystals for their base or nucleus, a somewhat different and larger type of dendritic crystallization then begins to form or rather grow inwardly into the mother liquid. The arrangement and direction of growth of these columnar dendrites is determined by the isotherms peculiar to the mold being used. Let us say that the mold in the present instance is rectangular in cross section. The isograph in Figure 2 shows that the center is the hottest part, and the corners, the coldest parts of the ingot. From the graph in Figure 4 it is

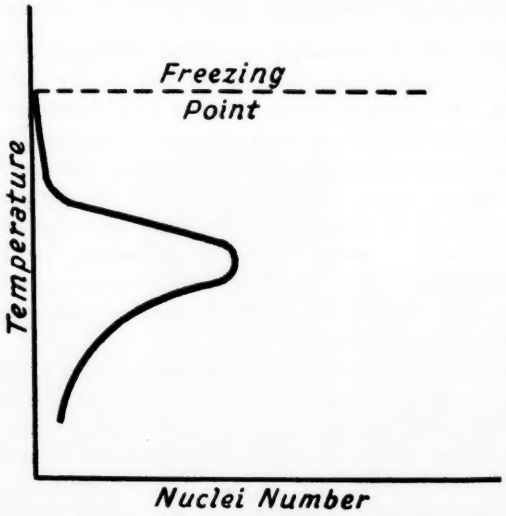

FIGURE 4—TYPICAL NUCLEI NUMBER-TEMPERATURE CURVE. (ROSENHAIN.)

evident that the greatest number of nuclei, and therefore crystals, will form at the corners, then, after an appreciable interval of time, a fewer number will form at the sides. The growth and orientation of these exceedingly long dendrites must needs be unidirectional, i. e., normal to the isothermal surfaces. True, crystal growth, if unimpeded, is invariably uniform in four directions. In this par-

ticular instance, however, the walls of the mold prevent growth outwardly; the growing arms or secondary axes of adjacent crystals soon meet one another and arrest all growth in any of the directions parallel to the walls of the mold; and the only direction remaining for uninterrupted growth is perpendicularly inward, where the metal is still too hot to allow of the formation of fresh nuclei. Columnar crystals may, or may not, fill up the whole of the ingot, depending on the conditions prevailing during solidification and the amount and kind of deoxidizers used. Generally, in large ingots and in heavy sections, the center is cooled down to the freezing point before the columnar crystals have grown across the ingot. If that be the case the remaining metal then solidifies from many independent centers, the result being a center made up of fairly fine equi-axed crystals arranged in no particular geometric pattern.

As the dendrites advance inwardly from the four enclosing walls, with cooling, they eventually collide into each other right on the geometric diagonals of the ingot. These diagonals, formed by the transcrystalline effect of the side walls, are clearly manifest in Figure 2.

Solidification is a three-dimensional phenomenon, i. e., metal freezes across as well as up the cast member. As a result, the cold ingot assumes a structural arrangement wherein it consists of four triangular prisms composed of long columnar crystals, one face of each prism corresponding to the interior face of the mold against which it formed. The growth of crystals from the bottom has proceeded in a similar manner, so that the four triangular prisms rest each on one face of a four-sided pyramid or base cone as shown in Figure 5. This mode of crystallization leaves the steel potentially weak at several places, namely: the junction of each columnar crystal with its neighbors; the junction of each set of columnar crystals; and the junctions of the columnar and the equi-axed crystals. A large number of the cracks occurring in steels either originate or eventually locate themselves in the above zones of weakness.

Some metallurgists distinguish between two kinds of solidification, i. e., progressive (laterally across the member) and directional (vertically up the member). In a great many instances, however,

it is exceedingly difficult to disentangle the two. Pointing out the differences between them, it is stated that transverse or lateral freezing, aside from engendering certain zones of weakness in the form of cleavage planes, plays a relatively passive rôle in the creation of defects. Because of this, foundrymen pay little, if any,

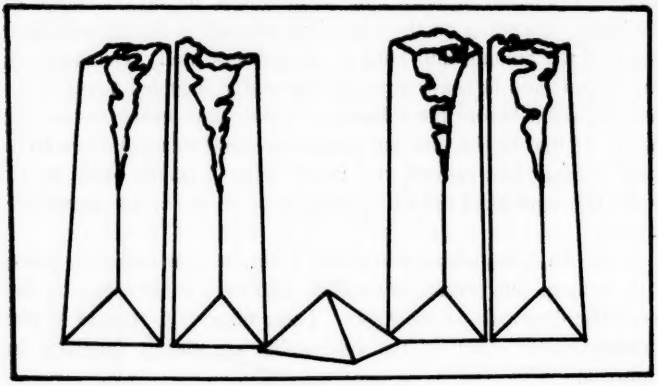

FIGURE 5—BREAKDOWN OF A HOT-CAST METAL INGOT SHOWING THE EFFECTS OF DIRECTIONAL GROWTH. (BREARLY.)

attention to it. Upward or vertical freezing, on the other hand, exerts a decided influence on the efficiency of the feeding system and, therefore, on the solidity of castings. If properly directed, it is a potent force for the promotion of integral soundness, but if allowed to proceed at random, without any attempt at regulation of temperature gradients, it will cause a disastrous proportion of the castings to be unsound. The fundamental difference between the two kinds of freezing is that the direction of the latter can be controlled, while that of the former cannot.

Concerning defects, in addition to the internal cracks referred to in the preceding paragraph, there are other serious solidification ailments from which castings frequently suffer, namely: pipe (major, secondary and micro), internal shrinkage draws and center-line weakness. The cause for their formation is the diminution in volume (approximately 3 to 5 per cent) which normally

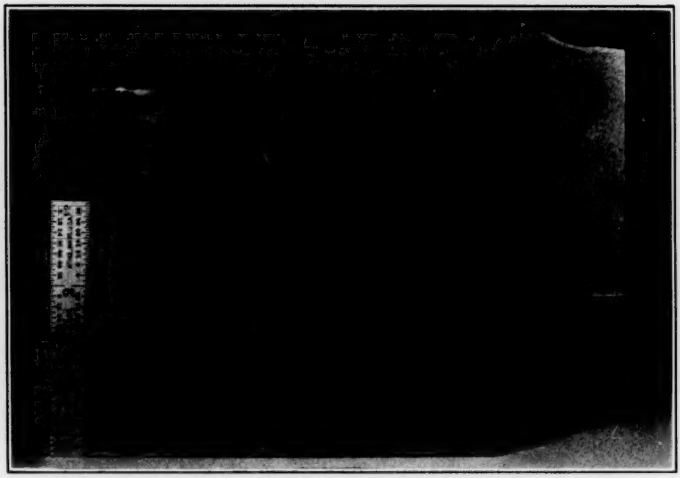

FIGURE 6—SECTION OF A STEEL CASTING SHOWING CENTER-LINE SHRINKAGE DEFECTS. NOTE THAT THEY ARE LOCATED IN THE NON-ORIENTED CENTRAL ZONE OF CRYSTALS.

occurs during the transition of the metal from the liquid to the solid state. As the outer layers of liquid metal become progressively densified by solidification, other liquid metal from the hotter interior portions flows outwards to the solid crystals which have already separated. So long as this influx of liquid metal to the solidifying areas can take place the production of a solid casting is possible; when the supply fails internal cavities result. Piping can be eliminated from the casting by localizing it in properly proportioned, suitably located, and efficiently feeding shrinkheads or risers.

The stubbornest of all defects is center-line weakness. It is a defective condition of metal consisting of tiny (micro and macro) crevices with dimensions often on the order of a fraction of a millimeter, with irregular and ragged outlines (Figure 6), and with non-oxidized walls. With reference to the equilibrium diagram of iron-carbon alloys, center-line weakness is believed to occur in the temperature range bounded by the liquidus and solidus lines, and is formed by the contraction on freezing of the last portion of the liquid enclosed by surrounding partitions. Thus, no center-line weakness is to be found in the oriented peripheral zone of castings and ingots in which basaltic crystallization progresses uniformly inward without encircling any remaining liquid. The defect is found, however, in the non-oriented central zone of crystals, where dendrites growing in various directions meet.

It has been reqeatedly demonstrated by good authority that compactness or freedom from the above defects can be obtained with controlled directional solidification. In Figures 7, 8 and 9 is indicated the manner in which a sound and an unsound condition of metal is obtained, using controlled directional solidification and an orthodox foundry method of casting, respectively. The contour lines mark the crystallization of successive skin thicknesses and show the progress of metal immobilization. In Figure 7 the example is top poured, there being no sand ingate to the mold. In Figure 8 the example is bottom gated as is customary with most steel castings, whilst in Figure 9 the example is bottom gated into the riser and, after pouring is completed, the mold is reversed through an angle of 180 degrees to bring the riser into its proper feeding position in relation to the casting. It will be seen that, while example

Figure 7 presents evidence of little or no adverse temperature gradient, example Figure 8 shows considerable evidence of such an adverse temperature gradient. Figure 9 illustrates how a favorable temperature gradient is produced with complete reversal of the mold. From a study of the sketches it is evident that soundness is assured only when the direction of solidification is progressively upward from the bottom to the feedhead of the mold. To insure

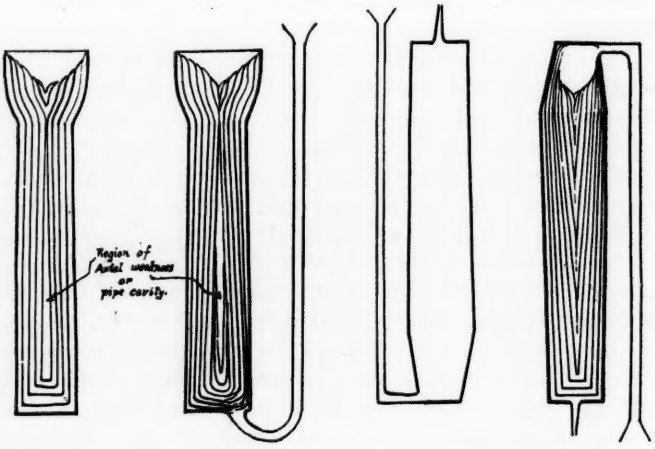

FIGURE 7
TOP POURED.

FIGURE 8
BOTTOM GATED.
(BATTY.)

FIGURE 9
180° REVERSAL.
(BATTY.)

freezing of the metal in the upward direction there must be imposed upon the cooling system a decided temperature difference between the top and bottom metal, i. e., the temperature of the metal in the feedhead must be higher than that of the metal in the bottom of the mold.

Practical difficulties often deter the establishment of a favorable temperature gradient in a great many castings, especially when orthodox foundry methods are followed in making them. The

difficulties can be circumvented, however, by an ingenious use of one or more of the following methods of casting manufacture:

1. Banking or partial reversal, 20-45 degrees.
2. Top pouring of risers.
3. Heading.
4. Gating—parting, multiple and stepwise.
5. Chilling, coring, design.
6. Padding—outside, inside, eccentric.
7. Sectioning or partitioning of castings.
8. Preheating the cope.

Part III—Specific Cases.

(1) Anchor Shanks—Illustrating Control by Banking.

Of the many marine castings that the foundry makes, anchor shanks are probably the most adaptable to controlled solidification. With reference to their geometry, they are long, slightly tapered, solid members of rectangular cross section with liberally radiused corners. Their design is completely free from re-entrant angles, differential sections and changes in direction. The absence of all but one small internal core in the shackle bolt hole also makes for integrity in the subject castings. Figure 10 depicts the general outline of a shank for a 20,000-pound stockless anchor, with gate and feedhead attached.

The procedure of mold manipulation involved in directing solidification up the shank is quite simple, the mold being tilted at a small angle (20 degrees) on a bar or rail on the foundry floor so that the ingate and feedhead are located at the low end of the mold. After pouring is completed and the vent sealed, the mold is reversed through an angle of about 20 degrees to bring the feedhead into the requisite superior position in relation to the casting.

Using the above practice, it is possible to produce overall temperature gradients of approximately 700 degrees-900 degrees F. in the shank. Inasmuch as the efficiency of the feeding or heading system is a function of the temperature gradient imposed on the solidifying metal, it is apparent that whatever can be done to widen the temperature gap between the vertical extremities of a casting will result in a sounder product. In this connection, the

following additional steps are taken to secure a steeper heat gradient: (1) slow pouring; (2) filling feedheads from the top; (3) heat-insulating the top of feedheads.

It is not difficult to see how slow pouring creates increased temperature differences. Metal solidifies as a result of transference of heat from itself to the mold. In its transit through the mold it cools by an amount which is proportional to the duration of its contact with the mold, and the ratio of the contacted mold area to the thickness of the metal stream passing over it. The essential feature of pouring, therefore, is that the molds shall be filled as slowly as practicable. Too rapid filling of the mold results in greatly reduced temperature gradients, and oppositely, too slow pouring is productive of castings having a defective surface—scabbed and pock-marked on the cope side. Scabbing, by slow pouring, occurs in the following manner. The drag or bottom surface of a mold generally escapes injury because the weight of the overlying hot metal overwhelms all lifting and bulging forces generated within it. No such damping action is exerted on the disruptive forces acting on the cope or top surface. Here the intense radiant heat given off by the slowly rising metal beneath acts on the cope, causing it to crack and swell. The cracked and loosened surface is then either pulled down by gravity or dislodged by the wiping action of flowing metal. This burning down of the cope can be remedied in one of four ways—faster pouring, more thorough nailing of the cope surface, an increased use of crabs in the cope, or strengthening the bond of the sand in the cope with more bentonite. The subject shank was poured with approximately 1.0-inch rise of metal in the mold per second. This speed was obtained with a 2½-inch pouring nozzle and a 4-inch ingate.

A word is probably in order concerning the effect of casting temperature on the quality of the metal. Pouring temperatures which are too low, even if sufficiently high to avoid cold shuts, may not permit risers to perform their primary function of feeding the casting or to carry off slag, dirt and dross. Casting temperatures on the other hand which are too high, aside from increasing liquid shrinkage and quite apart from other disadvantages attaching to them, reduce the rate of solidification, because the excess heat of the metal is communicated to the mold before the freezing point

of the metal is reached, so that the thermal capacity of the mold is largely exhausted before solidification begins. The resulting very gradual solidification produces not only a very coarse structure, but allows of the occurrence of serious segregation. It is, therefore, an almost universal rule that casting temperatures should be kept as low as possible, consistent with adequate fluidity of the metal to allow of the proper filling of the mold. The approximate casting temperature of the metal used in making the shanks was 2850 degrees F.

It was stated earlier that the practice of filling up feedheads from the top, after the pouring of the casting proper is completed. is further assurance that the metal in the upper levels of the mold will be hottest. Covering the risers with anti-piping material retards their cooling considerably and thus it, too, tends to promote better feeding. The riser on all shanks was treated in just such a manner.

The data given below relate to a shank for a 20,000-pound anchor. It will be noted that dry steel facing sand and used sand-blast sand were used in making the mold and core, respectively. The reason for this is that the relatively harmonious design possessed by the shank presents no problem in mold resistance. Sand-blast cores impart a very smooth finish to the casting surface; they are not used where a high order of ready and immediate collapsibility is desired.

Mold Materials.

Facing sand (Table I)	No. 2i
Backing sand	No. 4b
Core	No. 5e

Steel Data.

Grade	Bw
Pouring temperature, degrees F.	2875
Nozzle size, inches	2½
Pouring time (not including riser), seconds	25
Rate of metal rise in mold, inch per second	1.0

General Founding.

Banking angle, degrees	20
Temperature gradient obtained, degrees F.*	950
Size of feedhead	17″ rd. × 26″ by 1000#
Size of ingate, inches	4
Weight of shank, riser and gate, pounds	5900
Weight of shank, pounds	4820

Heat Treatment.

Upheat, hours	18
Hold, hours	30
Temperature, degrees F.	1650
Cooling, hours in furnace	24

(2) ANCHOR CROWNS—ILLUSTRATING CONTROL BY TOP POURING OF RISERS.

Instances where top pouring is employed, per se, as a means to secure directional solidification are rare; instances where it is used conjunctively with other methods are legion. Top pouring is accomplished in one of two ways—either the casting together with its risers, or the risers alone, are top poured. When it is not feasible to pour a casting via a top gate for fear of excessive erosion of the mold, the next best procedure is to bottom pour the casting up to the level of the risers, and then top pour the risers. The latter practice is the more common.

Concrete examples illustrating the employment of the latter method for directing solidification are anchor crowns and large monel metal propellers. Both of these castings, by design, are subject to differential freezing. The thin flukes on the anchor and the thin blades on the propeller congeal rapidly, while the more massive sections, particularly the feedheads, remain fluid for a long time. Even if the above were to be bottom poured completely, it is apparent that the adverse temperature gradient produced by bottom pouring would not only be short-lived, but would soon reverse itself into a favorable one by the lower surface area to volume ratio of the heavier base and feedhead sections.

* Measured with thermocouples immersed in metal to a depth of 1 inch in the bottommost and topmost locations of shank.

The remarks made under Anchor Shanks concerning the speed of pouring, temperature of metal and mold resistance are also applicable to the crown. The following data pertain to the making of 20,000-pound anchor crowns:

Mold Materials.

Facing sand	Cope	Nos. 3d, 3e
	Drag	Nos. 2i, 2j
Backing sand		No. 4b
Internal cores		No. 5e
External cores		Nos. 2i, 2j

Steel Data.

Grade	Bw
Pouring temperature, degrees F.	2850
Pouring nozzle, inches	3½
Pouring time (not including risers), seconds	55

General Founding.

Size of ingate (terra cotta), inches	4
Size of risers	2 — 11″ rd. × 14″ 1 — 24″ × 20″ × 30″
Weight of crown, risers and gate, pounds	19,300
Weight of crown, pounds	15,500

Heat Treatment.

Upheat, hours	18
Hold, hours	30
Temperature, degrees F.	1650
Cooling, hours in furnace	24

Two undesirable conditions attended the manufacture of large (20,000 and 25,000-pound) anchor crown, viz., scabbing of the cope surface and low dynamic strength at 42 to 52 degrees F. in the heavier sections.

Navy Department Specification 6A2 for Stockless Anchors requires that they be drop-tested from a 12-foot height. Figure 11 pictures a macro-etched section of an anchor fluke which had failed in cold weather in the drop test. The physical strength of the metal in close proximity to the fracture—and in the locations indicated on the photograph—is recorded in Table III of the Appendix. Susceptibility to cold brittleness under impact was apparently overcome by increasing the holding time, on annealing, from 30 to 38 hours, and by the employment of approximately 1000 pounds of internal chill bars (½ inch thick by 1½ inches wide by 12 inches to 36 inches long) arranged checkerwise in the flukes. It is the policy of the foundry to resort rarely to the use of internal chills, in fact, not at all, in small size sections (up to 9 inches thick). Regarding their use in heavy sections, there are occasions—such as this one—when their use is well nigh unavoidable.

Scabbing was eliminated to a large degree with faster pouring, with increased nailing of the cope, and by shading the cope with internal chills against the intense heat of rising metal.

(3) GLOBE VALVE BODIES—ILLUSTRATING CONTROL BY HEADING.

Control by heading is practiced on small castings whose design is either not amenable to, or makes uneconomical the use of, the reversal methods of casting. Favorable temperature gradients are produced by risers only when their ratio of surface area to volume is considerably less than the ratio of surface area to volume of the casting which they surmount. This is predicated upon the fact that the velocity of solidification is a constant, that is, that at any definite time after pouring the weight or volume of steel solidified per square inch of mold surface is the same (4). The curves in Figures 12 and 13 show the relation between the volume of steel solidified per unit surface area and the time which has elapsed after pouring. It is apparent from a study of the graphs that the ideal form of riser is, most probably, a sphere, but there are practical difficulties in the way of applying economically such a form of feeder. For the same volume, the next most efficient form of riser or reservoir of temperature is the cylinder. Following this come the square, and then the flat rectangular types of risers. To illustrate by way of a concrete example, the following are the

FIGURE 10—SHANK FOR 20,000 POUND STOCKLESS ANCHOR.

FIGURE 11—CROSS SECTION OF 20,000 POUND ANCHOR CROWN. OBSERVE THE SOLIDITY OF METAL. SQUARES MARK LOCATION OF TEST SPECIMENS TAKEN FOR TABLE III.

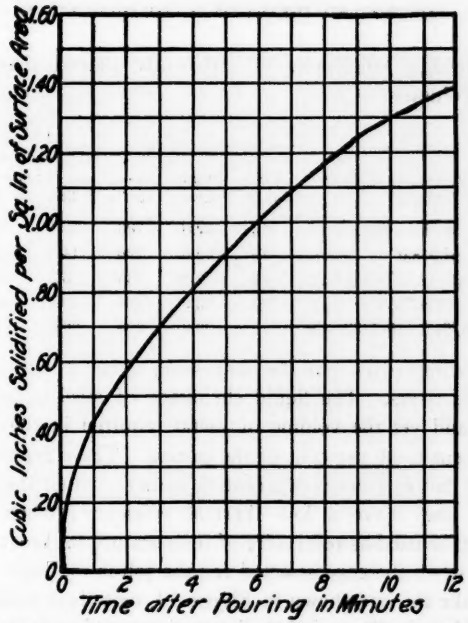

FIGURE 12—RATE OF SOLIDIFICATION OF STEEL IN DRY-SAND MOLDS, WITH RELATION TO SURFACE AREA. (AFTER BRIGGS & GEZELIUS.)

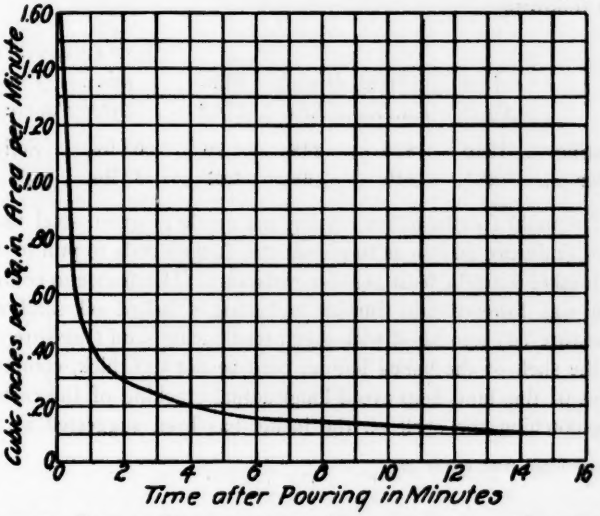

FIGURE 13—RATE OF SOLIDIFICATION OF STEEL IN DRY-SAND MOLDS BASED ON VOLUME. (AFTER BRIGGS & GEZELIUS.)

relative feeding efficiencies of differently shaped risers, but of identical volumes:

Form and Dimensions of Riser Inches	*Vol. Cu. In.*	*Wgt. Lbs.*	*Area Sq. In.*	*Amount Solidified in 1 min.* *Lbs.*	*Cu. In.*	*Time to Completely Solidify Mins.*
Sphere: 6" in diameter.....	113	32.0	100	12.1	42.7	7.2
Cyl.: 4¼" rd.×8.0".....	113	32.0	120	14.5	51.2	4.7
Square: 3⅝"×3⅝"×8⅝".....	113	32.0	135	16.3	57.5	3.6
Plate: 2¼"×6¼"×8"	113	32.0	160	19.4	68.4	2.7
Plate: 1-25/64"×10-5/32"×8"	113	32.0	220	26.6	93.8	1.5

Steel castings often give the impression of being too heavily burdened with risers. The liquid shrinkage of steel is only 3 to 5 per cent, and yet the volume of metal required in the feedheads is 25 per cent to 50 per cent of the casting. There are times when the use of large risers is warranted, namely: when their form is such that they have a low thermal efficiency; when they are intended to be used as reservoirs of temperature to direct solidification; and when the cope selected for the job is too high. Flanged castings, like the one shown in Figure 14, owe their solidity to the very effective feeding of their large risers. The area-to-volume relation between the casting of Figure 14 and one of its risers is the following:

	Area Sq.In.	*Volume Cu.In.*	*Weight Lbs.*	*Ratio V/A*	*Metal Immobilized * 2 mins. After Pouring*	*3 mins.*
Casting	1240	875	248	.70	203 lbs.	Solid
Riser	224	240	68	1.07	37 lbs.	46 lbs.

The mold for the above casting was made in green steel facing sand (mixture 1d) so as to permit the flanged ends to pull toward each other with the least possible resistance. Hindrance to contraction was lowered still further by using a baked oil sand core (mixture 7d) topped off with green steel facing sand (mixture 2a). If the shell of the baked bottom core be not too thick, composite cores of this kind help avoid longitudinal cracking of the casting. Vee-notching the shell on the inside has been suggested as still

* Calculated from Figure 12.

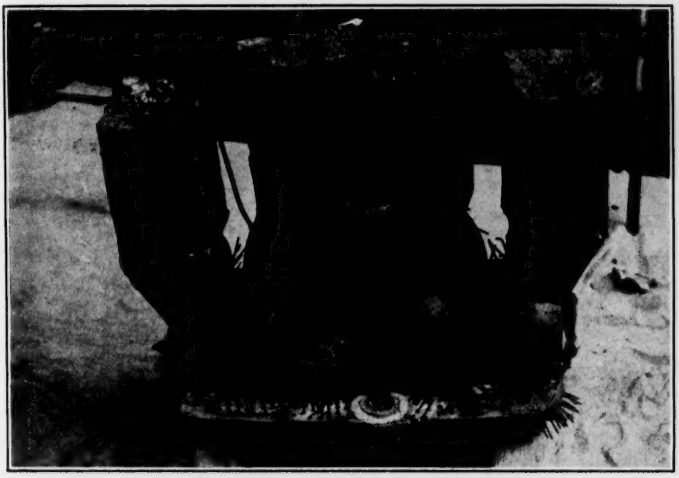

FIGURE 14—7-INCH VALVE BODY—ILLUSTRATING CONTROL OF SOLIDIFICATION BY HEADING. OBSERVE THE SMOOTHNESS OF THE STEEL SURFACE.

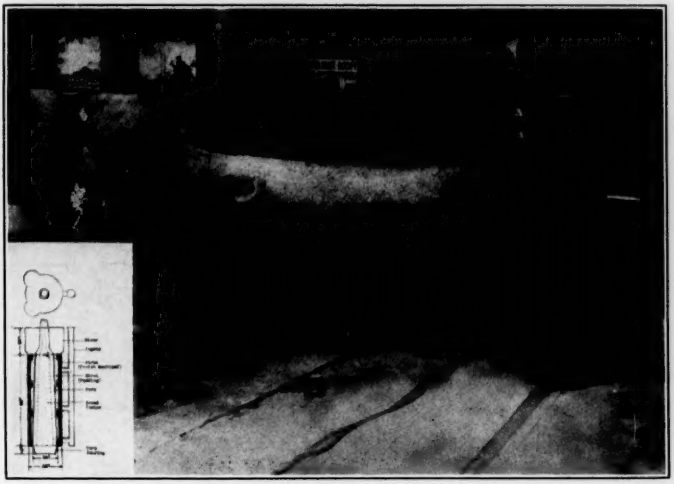

FIGURE 15—TWO-ARM STRUT, AS-CAST, SHOWING GATING, RISER, AND OUTSIDE PADDING.

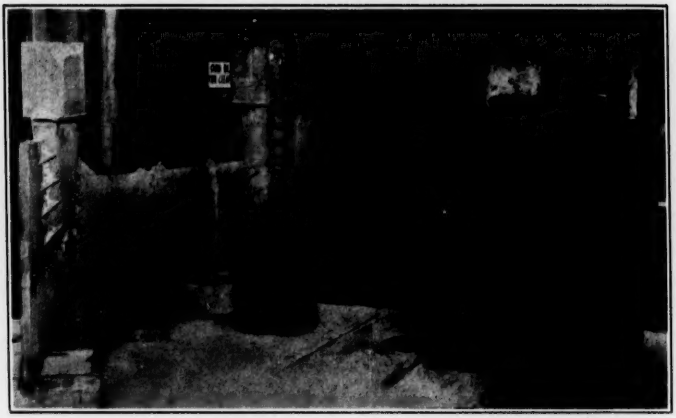

FIGURE 16—TWO-ARM STRUT, AS-CAST, SHOWING DETAIL BETWEEN THE ARMS.

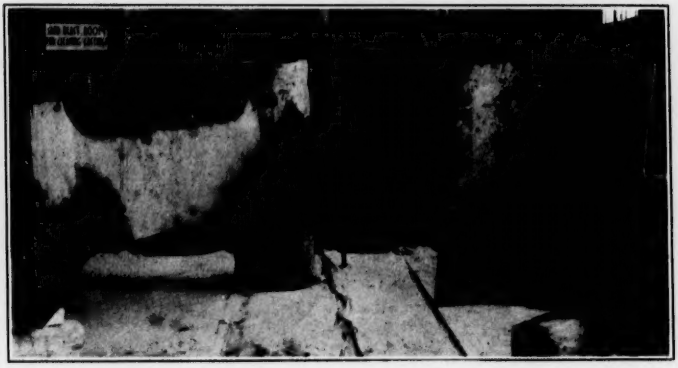

FIGURE 17—TWO-ARM STRUT, FINISH-MACHINED.

another possible means for increasing core collapsibility. Attention is directed to the smoothness of surface possessed by these castings.

(4) STRUTS—ILLUSTRATING CONTROL BY GATING.

Gates, the actual points at which molten metal enters the mold, not infrequently provide an excellent means for directing solidification. Of the three fundamental classes of gates—top, parting and bottom—only the first two are capable of producing favorable temperature gradients. This they do by virtue of their elevated location. All other things remaining equal, it is obvious that the portions of the casting farthest away from the gate or entering point of the metal will freeze first and that freezing will tend to be directed from this farthermost position towards the gate. Thus a gate situated at or near the top of the casting will direct solidification up to itself; while a gate situated at the bottom of the casting will, by the same token, direct solidification down to itself. The direction of the latter, as explained elsewhere, is counter to that required for efficient feeding.

Large castings are rarely, if ever, top gated. No sand mold can withstand for long either the cutting action or the impact of a vertically falling column of steel. The attendant bottom splash and turbulence of metal also inflict severe damage upon the casting. Because of this, parting and bottom gates are used almost exclusively. Parting gates are considerably less damaging in their effect upon the mold. In fact, the tendency to mold erosion is almost entirely eliminated when several of these gates supply the metal to the mold simultaneously. Multiple gating slows down the speed of the metal, causing it to run down the banks of the mold in quiet, and smoothly descending streams. Parting gates of the multiple type are shown in Figures 14, 20 and 23. Bottom gating, despite the adverse temperature gradients it creates, enjoys the greater popularity among foundrymen. It is regarded as being the orthodox method for gating castings. The reason for its widespread popularity is its ability to introduce metal into the mold with a minimum of metal and mold disturbance.

On occasion, bottom gating can be made to function in a manner analogous to top gating. By way of an actual illustration, reference is made to Figure 15, which shows a large strut casting with

a single downrunner or sprue connected to the hub section through three gates. All three of them lie in the same vertical plane, but at different elevations—one at the bottom, one in the middle and one close to the top. During the pouring of the mold, nearly all the metal in the lower levels is introduced by way of the bottom gate; that in the higher and topmost levels, by way of the middle and top gates respectively. And lastly, after the casting proper has been poured, each of the three risers is individually top poured. Immobilization of metal in the direction of the feedheads is further assured by the internal padding of the bore (obtained by putting a .44 inch per foot taper on the core) and the placement of two external metal mounds directly over the junction between each arm and hub. By gating and padding in this manner, and top pouring of risers, there is thus produced a pronouncedly favorable temperature gradient in both mold and metal which permeates throughout the whole casting.

Five to eight minutes after pouring, the drawbacks in the mold are loosened to permit the casting to move in with the least possible mold resistance. Twenty minutes after pouring, all mechanical restraint on the drawbacks is removed.

Until the above practice had been developed, considerable difficulty was experienced in obtaining good castings. The substitution of external pads for external chills between the arms and hub, and the employment of a readily detachable green sand drawback in the crotch, aided greatly in the production of sound struts.

The mold for the above casting consists essentially of a large drag and three small copes for the risers. In the drag, and in between the arms of the strut, there are three drawbacks—one against each of the two arms and one in the crotch of the arms. Both dry and green sand mixes have been successfully used in the two arm drawbacks, the green sand generally yielding the superior product with respect to surface appearance and freedom from hot tears between the arms and the hub. The core is made from dry steel sand (mixture 2i) and extends beyond the top of the riser. Preceding the positioning of drawbacks and cores, the mold is dried with salamandrine heat. Four-inch terra cotta sleeves are used for the gates and sprue. The following additional data give information on the amount of metal in risers and padding:

	Pounds	*Per Cent*
Weight of casting with gates and risers attached	14,200	100
Finish-machined weight of casting	7,140	50
Gates and risers, ribs and fins	2,800	19
Outside padding (mounds)	700	5
Metal removed from bore	3,560	26

(5) LOW-PRESSURE TURBINE CASTINGS—ILLUSTRATING CONTROL BY CHILLING.

Present-day foundry technology looks askance upon the use of internal chills, and seldom relies upon external chills alone for controlling the direction of solidification. The primary purpose of externally applied chills, as used today, is to eliminate adverse local temperature gradients set up at junctions of thin and thick sections, and at locations of extra mass (hot spots) found at positions of joining sections. Hot spots and junctions of dissimilar sections are the loci of stress generation, stress concentration, and hot tear formation. This is so for the reason that thick sections require more time for solidification and cooling than thin sections. It is not impossible for a thin section integrally connected to a heavier one to be completely solid and appreciably cooled while the heavier section is still solidifying. The temperature gradients so established will result in different rates of contraction and, hence, the formulation of stress. Centralization of stresses occurs at sharp corners and abrupt changes in section. Cracking will occur at the weakest section, which, of course, will be the hottest section.

Hot spots may be searched out by the inscribed circle method of Heuvers (5) as illustrated in Figure 18(a). They can be eliminated with design, external chilling and internal coring. The first and last operate by equalizing the sections; chills, by equalizing the rates of cooling of different sections. The joints shown in Figure 18 illustrate the five basic ways in which sections joint, and the manner of mass distribution necessary for the avoidance of hot spot formation. Excepting for the arrangement and a few minor modifications, the original sketches are those of Briggs, Gezelius and Donaldson. It is evident that not all liberal radii are beneficial—those imposed upon the joint by the addition of metal aggravate the temperature gradient in the hot spot; those formed by the

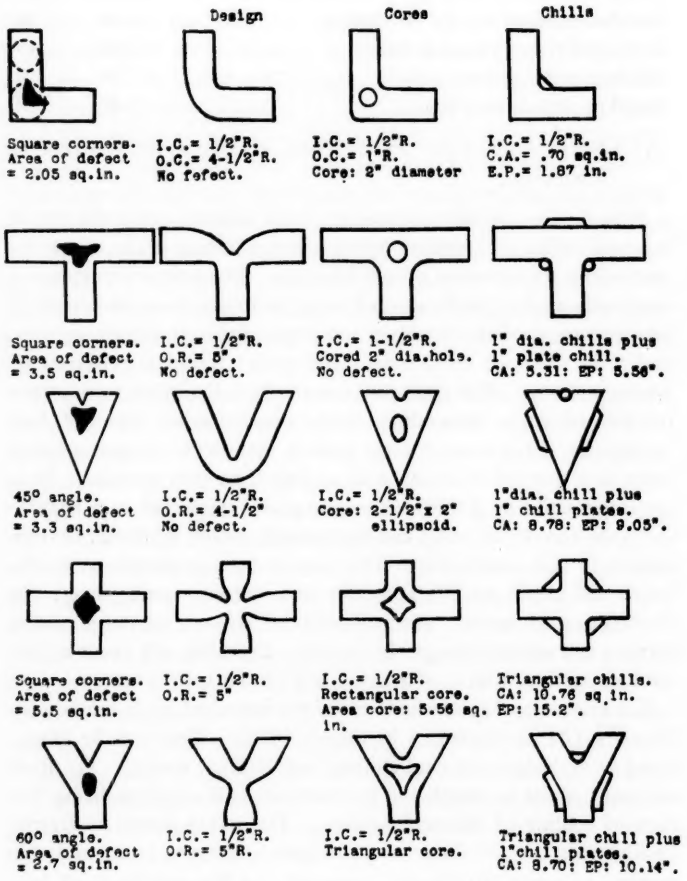

FIGURE 18—SHOWING 5 FUNDAMENTAL JOINTS AND HOW THEY CAN BE MADE SOLID.

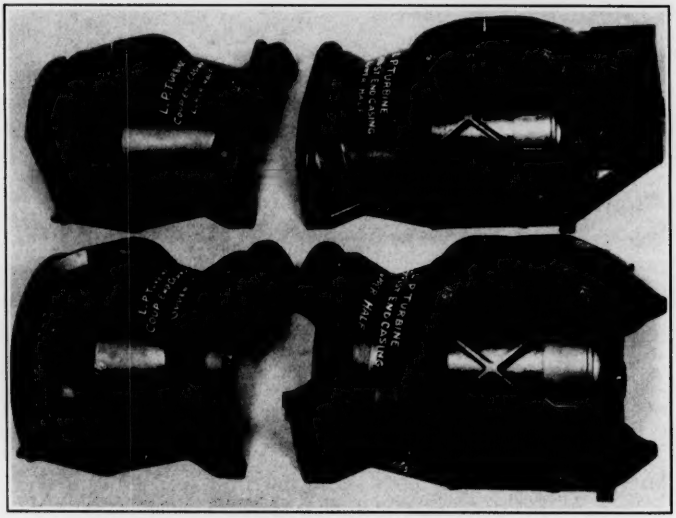

FIGURE 19—I. P. TURBINE CASING—SHOWING V, Y, AND X JOINTS.

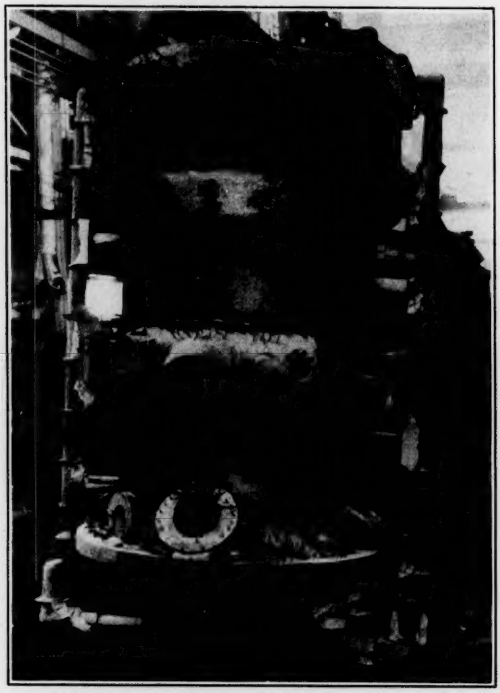

FIGURE 20—H. P. TURBINE CASING (TOP HALF)—ILLUSTRATING APPLICATION OF CHILLING FOR CONTROLLING SOLIDIFICATION.

subtraction of metal, ameliorate it. It must be remembered, too, that though some designs are excellent from the standpoint of obtaining solidity of section, they may be very poor designs from the standpoint of uniform transmissibility of stress.

Actual instances illustrating the application of chilling to areas harboring local adverse temperature gradients are shown in Figures 19 and 20. In Figure 19 there are evident numerous V, X and Y joints, some very remote from the feedheads. Using the method of inscribed circles for determining the size of hot spots, the diameter of the inscribed circle at the intersection of the X is 1¾ inches as compared with that of ¾ inch in the intersecting arm. The hot spot in each of the X joints was eliminated by means of four large triangular chills—two $3 \times 3 \times 5$ inches, and two $2 \times 2 \times 3$ inches in cross section. The total effective perimeter and the cross sectional area of the four chills were 20 inches and 12.5 square inches, respectively. No chills were used on the V or Y joints. Instead, the entire joint in every case was tapered (¼ inch per inch) and the leg of the Y spread as pictured. In this manner the potential area of shrinkage was chased into the padding on the inside of the casing, whence it was removed, with the padding, during rough machining. Radiographic inspection of the joints found them to be sound.

Figure 20 is an example of a more extended use of chilling for the control of solidification. It will be noted that nearly every re-entrant angle contains a chill. The manner of abstracting heat from heat-retaining pockets is clearly manifest. Chills are present in all places where adverse temperature gradients tend to build up, viz., at the foot of isolated pads, bosses, flange necks, and at the intersection of all planar surfaces. One-inch round steel chills were used on the subject casting. Comparing chilling methods with padding methods, it is stated that a greater degree of soundness is obtained in castings of the subject type with the latter.

(6) STRUTS AND TURBINE CASINGS—ILLUSTRATING CONTROL BY PADDING.

Struts:

Molds of big-end-up design were proposed and used experimentally by steel-producing plants more than 50 years ago. Since that time they have been more and more widely used in industry,

until today their use is well nigh universal. Despite their widespread use of their proven worth in the manufacture of ingot steel, tapered molds were not used by foundrymen for many years. It is only recently that steel foundries began applying taper to steel castings. Foundrymen are now convinced that—in order to avoid loose texture and axial shrinkage cavities in the body of a massive casting—the chamber of the mold must be of big-end-up design and enough larger in top cross section than in bottom cross section so as to cause the metal to solidify progressively upward.

There are still many foundries which are loath to adopt the tapered or padded design because, in their opinion, it adds unduly to the cost of production. The Yard's experience negates this argument. The cost of patterns for padding, the cost of the steel in the padding and the labor involved in its removal, plus the increased cost of heat treatment due to longer soakouts at the annealing temperature, add up to a very small sum indeed, when compared with that normally expended upon their repair (preliminary exploring, bottoming out, welding, re-X-raying, stress relieving, pressure testing) of defects inherent to the unpadded design, or the replacement of the entire casting with a second—or possibly a third—new one. The consequent loss of time and delay in production is also costly.

The only disadvantage attaching to the padded design is the diminution in strength and ductility suffered by the casting. This is the penalty exacted by increased mass. Inasmuch as the application of padding herein was restricted to one side only (the other side always retaining the cast skin), the deleterious effect due to mass was slight. The outside metal on heavy castings is generally of excellent quality to a depth of one inch, possessing physical properties often comparable to those of individually cast coupons (see Figure 11 and Table III of the Appendix). The fact should not be overlooked that the steel castings industry is producing castings of highly complicated design that have remarkably uniform properties throughout sections of unequal mass. Such uniformity in properties is achieved by skillful gating and molding practices, by good melting technique, and by subsequently heat treating the castings in a way to minimize as much as possible the influence of change in section.

It is added that all welding of minor defects and structural attachments is done after annealing. Annealing also precedes all chipping and rough machining operations. Castings have been irreparably damaged by having been welded and by having been chipped in the green state.

The strut in Figure 21 is an example of padding as applied to a horizontally made cylinder. The barrel is 66 inches long with outside and inside diameters of 25 inches and 18 inches, respectively. To obtain directional solidification the walls are eccentrically tapered from a minimum thickness of 3 inches in the drag to a maximum of 4 inches in the cope. Further steepening of the temperature gradient is secured by top pouring of risers and by their massiveness as well. Collapsibility in the core is obtained by topping it off with green sand.

An alternative method which is being contemplated for making intermediate struts is that employed on the main two-arm struts. Vertical molding is productive of a greatly reduced cope area and, therefore, of a greatly reduced number of cope defects.

The weights of the various components on a single-arm strut molded horizontally are presented below. In the data, the approximate cost of removing the padded metal from both the main and intermediate struts is also given. A close scrutiny of the cost data will disclose that the cost of padding is significantly lower than that indicated by the totals. The figures include, in addition to the cost of the actual padding itself, the removal of unpadded metal, i. e., that metal commonly designated as machining allowance. The figures, unfortunately, include the cost of counterboring, an expensive and time-consuming operation requiring approximately 56 hours.

General Founding.

Steel		Bw
Backing sand		No. 4a
Facing sand		No. 1d
Core mix	Bottom half	No. 2i
	Upper half	No. 2a
Gating	Size, inches	3
	Type	Bottom
Size of Risers		3 — 18″ × 8″ × 13″ 1 — 6″ rd. × 13″

Weight Distribution.

	Pounds	*Per Cent*
Weight of strut, with gate and risers attached	5988	100
Finish-machined weight of strut	2756	46
Weight of gate and risers	1750	29
Metal removed from bore	1482	25

Cost of Padding.

Item	*Intermediate Strut* (Figure 21)	*Main Strut* (Figure 15)
Metal	1482 × .01 = $14.82	4260 × .01 = $42.60
Heat treatment	1482 × .01 = 14.82	4260 × .01 = 42.60
Burning		570 × .004 = 2.28
Chipping		130 × .10 = 13.00
Rough machining	1482 × .03 = 44.46	3560 × .03 = 106.80
Total	$74.10	$207.28

Turbine Casings:

Casing design varies with nearly every turbine installation. Some new engineering findings or ideas are incorporated into each successive design. These, in turn, necessitate fitting changes in casing design. The designer's idea of what constitutes a fitting and proper design may or may not be in conformity with those basic foundry principles which govern the shape of castable structures. It eventually befalls the foundryman either to recommend a more castable design or to circumvent as best he can the disadvantage inherent in the design with sheer foundry technique.

Limitations of space prohibit extensive treatment of the manner in which troublesome points in casing design are solved. Briefly, in altering a design for founding, the fundamental considerations of efficient feeding and minimum internal stress govern every single modification.

Efficiency of feeding is generally effected by padding every component in the cross section of the casting. Side walls, vertical spokes, bolt bosses, isolated pads, flanges within wall sections, and all similar regions of extra mass are thus treated. Occasionally

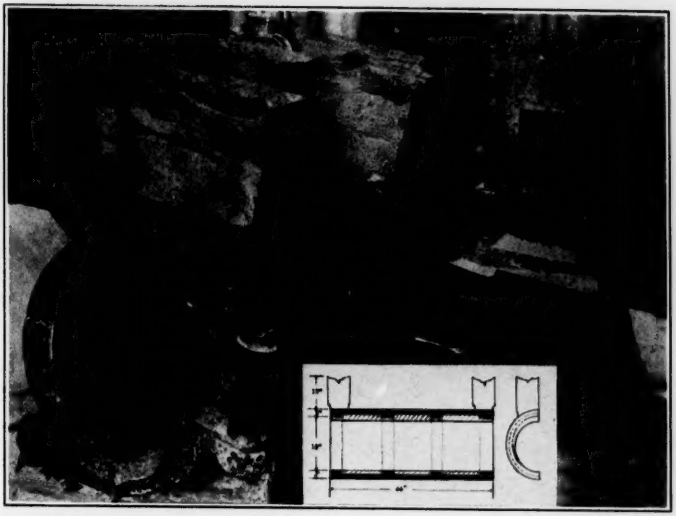

FIGURE 21—INTERMEDIATE STRUT, AS-CAST, SHOWING PADDING AS APPLIED TO HORIZONTAL CYLINDERS.

FIGURE 22—INTERMEDIATE STRUT, FINISH-MACHINED.

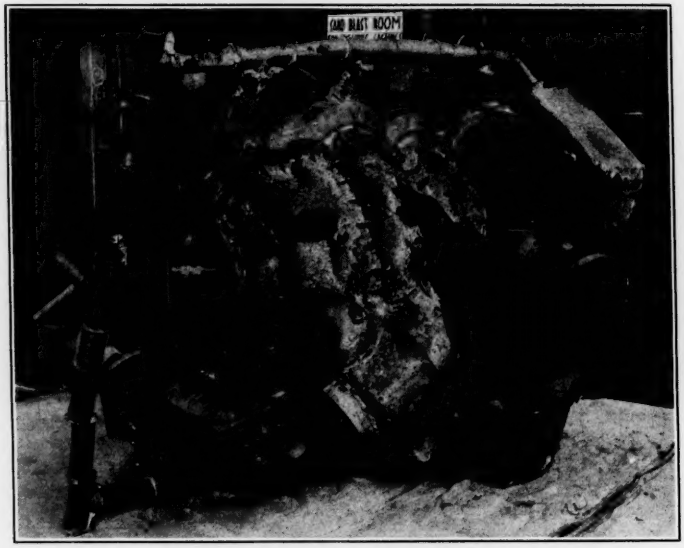

FIGURE 23—I. P. TURBINE CASING, AS-CAST, OUTSIDE VIEW, SHOWING GATING, BLIND RISERS, AND OUTSIDE PADDING.

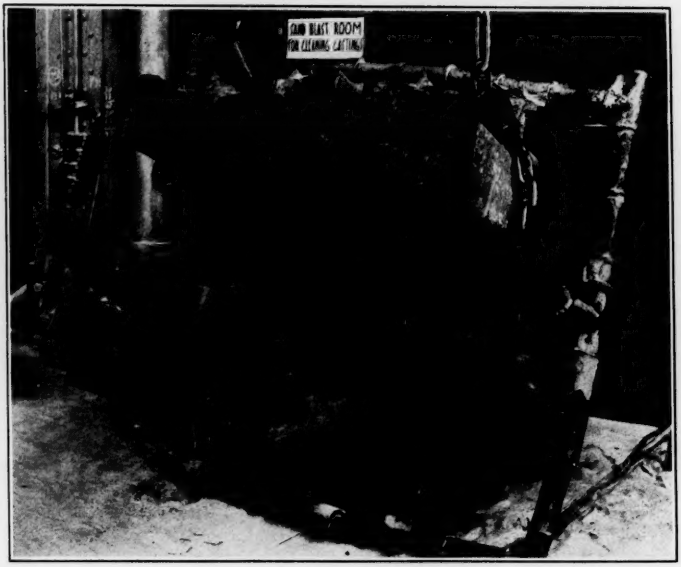

FIGURE 23A—I. P. TURBINE CASING, AS-CAST, INSIDE VIEW, SHOWING RISERS, GATES, AND PADDING IN BORE.

there appears a design wherein a light section is located between two heavy thicknesses of metal. Thin sections of this kind which interfere with the proper feeding of other more massive sections below them, together with tie bars and long connecting members, are best left out to be subsequently welded in with the metallic arc. Flanges likewise are made separately and then attached to the casting with welding. Sections which are beyond the reach of the main system of feedheads—particularly those located on the bottom of the casting and attached on all sides to members of much smaller thickness—are best supplied with feed metal from "blind" or closed risers surmounted with whistler risers for the escape of air. Thick, flat areas of metal—entirely surrounded by sections of equal thickness, but of lesser mass—are lightened to the weight of adjoining sections with a hole in their center. The practical handling of many of the foregoing points in design is illustrated in Figures 23 to 28, inclusive.

The amount of padding applied to turbine casings varies from 1/12 to 1/4 of an inch per inch, depending upon its relative position within the casting, its remoteness from the feedhead and the height and angularity of section. Thorough radiography of the casings (an average of 65 films per half casing) has shown that occasionally surprisingly thick pads are needed to eliminate all traces of center-line weakness. Padded metal is generally placed in those locations from which it can be most easily removed and on one side only, i. e., either on the outside or on the inside, never on both (opposite) sides simultaneously. Inside padding is preferred to outside padding, because it can be taken off more expeditiously. Manual chipping is employed for the removal of the latter, and mechanical boring for the former. Occasionally, outside padding lends itself to removal by machining.

As previously stated, the second fundamental consideration kept in mind when making changes in design is that of internal stresses. Internal stresses are fundamentally thermic in character and origin. Points on a casting between which dangerously high temperature differences might spring up are consequently vigilantly guarded against. Every design is carefully gone over for potential hot spots. The manner of their formation and elimination has already been related.

Hindered contraction stresses, too, are guarded against. Unlike the above, they have a mechanical genesis and act externally upon the casting. They are kept low in turbine molding by using green sand molds and collapsible cores. Turbine molds are faced with a layer of green sand two inches thick. The facing is hand-rammed; the backing up material is rammed with an air hammer. Six parting gates introduce the metal into the mold. Erosion of mold and core is prevented by nailing the facing with ½-inch head nails at an average density of one nail per every 2 square inches mold surface. At the mouth of the gates both core and mold are nailed with three nails to the square inch. Collapsibility in the core is obtained by making it with a relatively thin exterior shell (approximately 4 inches thick), with a hollow center, and a cast iron arbor so constructed that it can be easily broken when desired. The three cross bars connecting the main branches in the arbor are broken approximately 20 minutes after pouring. Summing up, it is stated that the principal reason why turbine casings and other complicated castings have not cracked by hot tearing is the fact that they have been made in green sand.

By actual measurement, temperature gradients of approximately 1200 to 1300 degrees F. have been detected in some of the subject casings. A study of the photographs in Figures 23 to 26 will disclose that all the practices for the control of the direction of freezing which have so far been described were used on the casing, namely: slow introduction of metal (obtained by dividing the entering metal among six gates); parting gates; massive, trough-like feeding heads; heat insulating of risers; padding; and chilling.

The following data give quantitative information on various phases of founding the pictured casing:

Founding Data.

Facing sand	No. 1d
Backing sand	No. 4a
Core mix	No. 7d*
Size of ingates (6 in all), inches	3
Pouring nozzle, inches	2½
Metal rise in mold, inch per second (average)	.7
Steel grade	C-Mo

* Pressure equalizing chamber and steam bleeder belt cores were made from mix No. 5e.

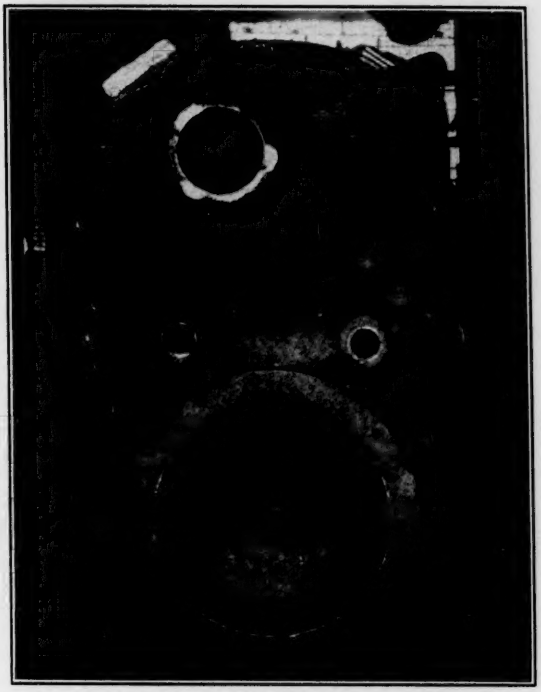

FIGURE 24—I. P. TURBINE CASING, OUTSIDE VIEW, RISERS AND GATES BURNT OFF, SHOWING SOME EXTERNAL CHILLS AND HEAVY OUTSIDE PADDING ENDING AT THE WHITE CHALK LINE RUNNING ON EDGE OF BOLT FLANGE.

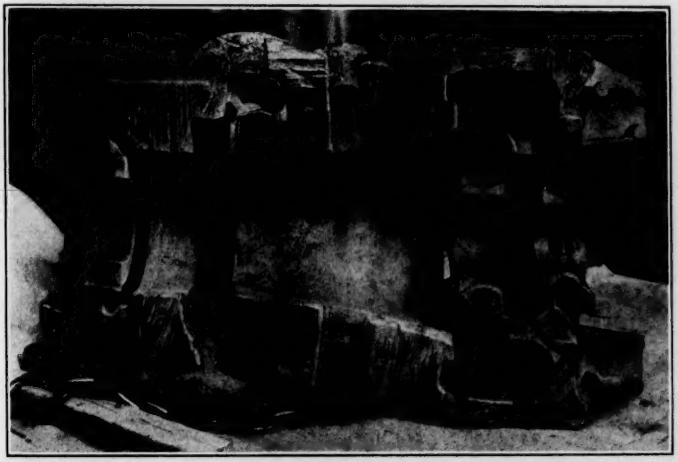

FIGURE 24A—I. P. TURBINE CASING, INSIDE VIEW, WITH RISERS AND GATES BURNT OFF, SHOWING HEAVILY PADDED BORE.

FIGURE 25—I. P. TURBINE CASING, OUTSIDE VIEW, WITH PADDING REMOVED. THE WIDTH OF THE BOLT FLANGE SHOWS THAT APPROXIMATELY 2 INCHES OF PADDED METAL HAS BEEN CHIPPED OFF.

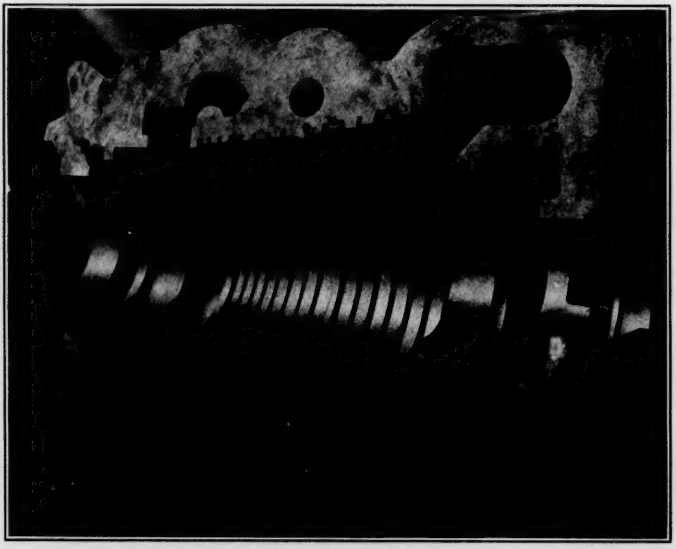

FIGURE 25A—I. P. TURBINE CASING, INSIDE VIEW, WITH ALL THE INSIDE PADDING REMOVED. THE STEAM BLEEDER BELT HOLE IS A GOOD LANDMARK WHEREBY TO GAUGE THE EXTENT OF INSIDE PADDING.

Weight Distribution.

	Pounds
Casing, with gates, risers and padding	10,153
Gates and risers	3,968
Outside padding	320
Metal removed from bore	1,570
Rough machined, including weldments	4,680
Weldments	385

Heat Treatment.

	Upheat	*Hold*	*Temp.*	*Cool*
Annealing (before chipping and machining)	6 hrs.	8 hrs.	1750° F.	FC
	4 hrs.	8 hrs.	1650° F.	FC
Stress relieving (after all welding)	4 hrs.	8 hrs.	1250° F.	FC

Cost of Padding.

Metal	1890 × .01 =	$18.90	
Heat treatment	1890 × .01 =	18.90	
Chipping	320 × .14 =	44.80	(60 man hrs.)
Rough machining	1570 × .08 =	125.60	(96 man hrs.)
		$208.20	

Using the above materials and practice, the cost per pound of the finished casting was 87 cents. This figure covers costs of pattern, castings, rough machining, testing and radiographing.

(7) THROTTLE VALVE BODY—ILLUSTRATING CONTROL BY SECTIONING.

The phenomenal strides which welding technology has been making for the past several years have won for it a permanent place in nearly all the metal working industries. Conservative designers and engineers are acknowledging it to be an invaluable tool, not only for minor repairs of surface defects, but for the construction of metal assemblies. There is now scarcely a single steel foundry without a weldery.

Not infrequently, the foundryman is asked to cast a structure whose design defies every attempt to control the direction of its solidification. Throttle valve bodies are an outstanding example of such a design. Since the chemistry of the castings mentioned herein is one which lends itself quite readily to welding, the most economical method, and sometimes the only method, whereby a sound condition of structure can be obtained in these complicated designs is to dissect them into several more simple and elementary sections, cast each individually, and then unite them with welding. This is precisely what was done to the throttle valve shown in Figures 29 to 31, inclusive.

It is seen that all the steam inlets were cast separately. The front and back plates, seats, brackets and nipples were cut from C-Mo plating. Regarding the body proper, it was made solid by means of four parting gates, 130 pounds of outside padding and eight bulky risers (6 inches × 10 inches × 11 inches) covered with head liquidizer compound. Hot tearing was avoided by making the body and its component parts in green sand molds and using cores made from oil sand topped off with green steel facing sand. Figures 29 and 30 show the extent of heading and padding, respectively.

Welding was performed in the flat position, using 3/16 and 1/4 inch diameter electrodes and 300-500 degrees Fahrenheit of oxy-acetylene preheat. Joints were veed to a 45-degree bevel with a root spacing of 1/4 inch and were backed up with a machined backing ring. Deposition was effected layerwise, using a weaving technique. The branches were welded into position one at a time. All welded joints were then X-rayed for soundness and the entire weldment stress relieved at 1250 degrees F.

The molding materials and the amount of metal used in the various components of this structure were as follows:

Molding Materials.

Facing sand		Nos. 1c, 1d
Backing sand		No. 4a
Cores	Upper halves	No. 1d
	Lower halves	No. 7d

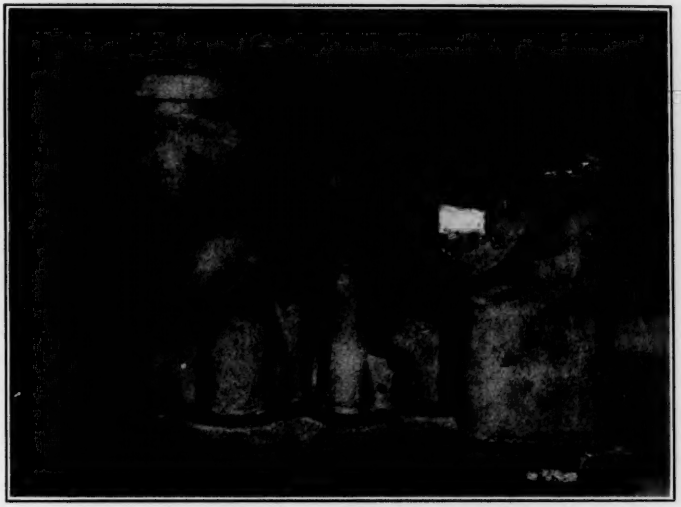

FIGURE 26—I. P. TURBINE CASING, OUTSIDE VIEW, SHOWING WELDED ATTACHMENTS. NIPPLES, BRACES, FLANGES, PLATES.

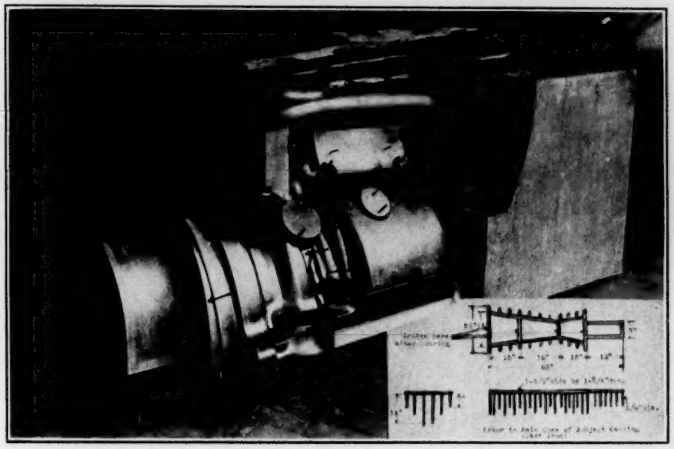

FIGURE 27—PATTERN FOR HP TURBINE CASING, UPPER HALF, SHOWING OTHER INTERESTING POINTS IN DESIGN. ARROWS POINT TO PADDING.

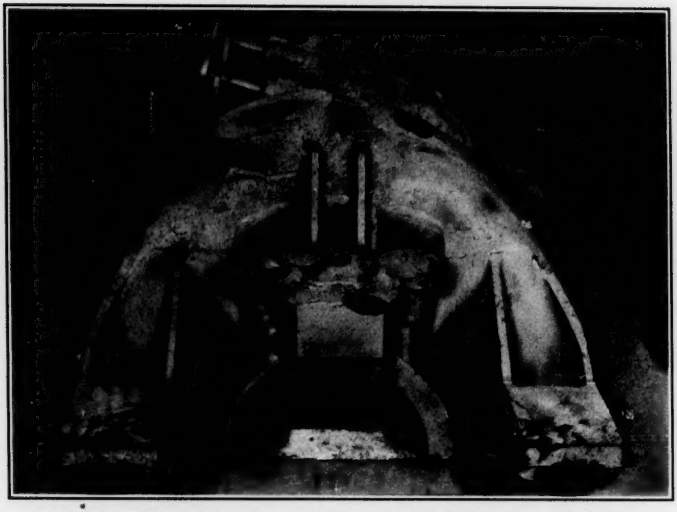

FIGURE 28—I. P. TURBINE CASING, LOWER HALF, SHOWING END LIGHTENING HOLES CUT IN SOLID CASTING AND VARIOUS WELD ATTACHMENTS.

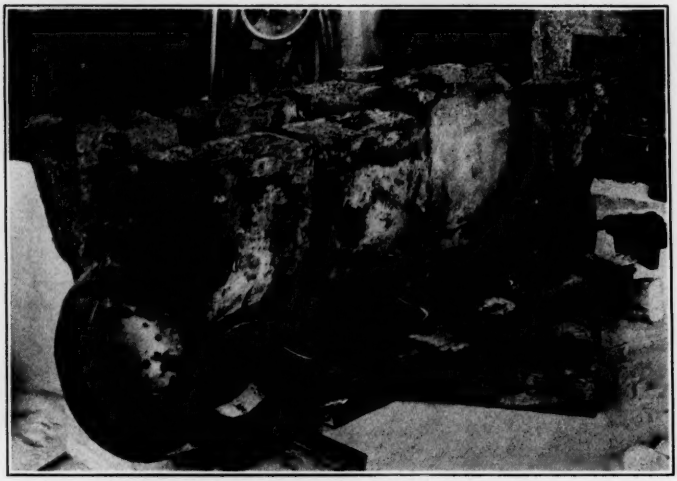

FIGURE 29—C-MO THROTTLE VALVE BODY—AS-CAST, SHOWING PARTING MULTIPLE GATES AND RISERS.

Weight Distribution.

	Pounds
Weight of body, with risers and gates	3198
Finish weight of body	1688
Risers and gates	1440
Outside padding	130
Weight of components, branches, etc.	1177
Entire welded assembly	2865

Latest practice has succeeded in making sound throttle valve bodies with some of the branches integrally attached to the body. The throttle valve of Figure 32 was made in such a manner. It is apparent that only half of the branches, i. e., either all the upper or all the lower flanged sections, are integrally castable. The flanged sections were made in the cope. The T-shaped bosses which are evident in the picture were made to provide a seat for subsequent weld attachments. Integral castings cost approximately $125.00 to $150.00 less, and can be made in approximately two weeks less time than those put together by welding.

Other important castings which are being cast in sections and welded together into composite structures are certain types of turbine casings and heavy ring sections. Thermit welding is being contemplated as a method for joining the latter.

Heavy ring sections have been made solid by applying directional solidification principles to them. Careful study of the casting will identify the following points of practice as being instrumental in obtaining the desired temperature gradient:

1. Positioning the lighter portion of the ring in the bottom of the mold and the more massive parts directly over it.
2. Chilling the bottom corner sections with "kool-head" chill nails (three per square inch and extending into the mold cavity 2 inches).
3. Denser nailing of the bottom surfaces of both core and mold.
4. Light padding on one of the upper vertical members.
5. The employment of massive risers and the top pouring of same.

Figure 33 shows the tight texture and compactness of metal obtainable with the above practice. Both the mold and all cores were made of sandblast mix No. 5c.

(8) CONTROLLING THE DIRECTION OF FREEZING WITH PREHEATING OF THE COPE.

Because of certain practical difficulties, the use of preheating on the cope to retard the chilling of feedheads, and thus increase feeding efficiency, has not been tried on any large casting. It is mentioned in this discussion as a possible method, for it is not entirely impracticable, providing the proper facilities are available.

APPENDIX.

An examination of the data contained in Table I discloses the following facts:

Green Sand:

(*a*) Air drying increases the permeability as well as the compression and shear strength of green molding sands.

(*b*) Air drying for periods in excess of 60 hours affects disadvantageously their physical properties. Skin drying with a gas torch, however, nullifies the deteriorating effects of setting or drying time. Specimens air dried for 120 hours, and then torch dried, have physical values equal to those dried for 1 hour at 225 degrees F.

(*c*) Spraying the molds with molasses water for the preservation of the surface does not deleteriously affect the molds. Permeability or the ability of a mold to vent its gases, is lowered by approximately 6 to 8 per cent.

Dry Sand:

(*a*) Drying at 500 degrees F. is productive of the highest physical properties in the sand.

(*b*) At least an 8-hour sojourn at the drying temperature is required for good results.

(*c*) Washing the molds with silica wash exerts a pronounced choking effect upon their permeability. Breathing efficiency is lowered by approximately 60 per cent.

FIGURE 30—C-MO THROTTLE VALVE BODY—RISERS AND GATES BURNT OFF. BOTTOM SIDE FACING FRONT. NOTE PADDING STARTING FROM ZERO ON BOTTOM AND RUNNING ¾ INCH DEEP AT MIDDLE (PARTING LINE). PADDING ON OPPOSITE SIDES RUNS SLIGHTLY OVER AN INCH DEEP.

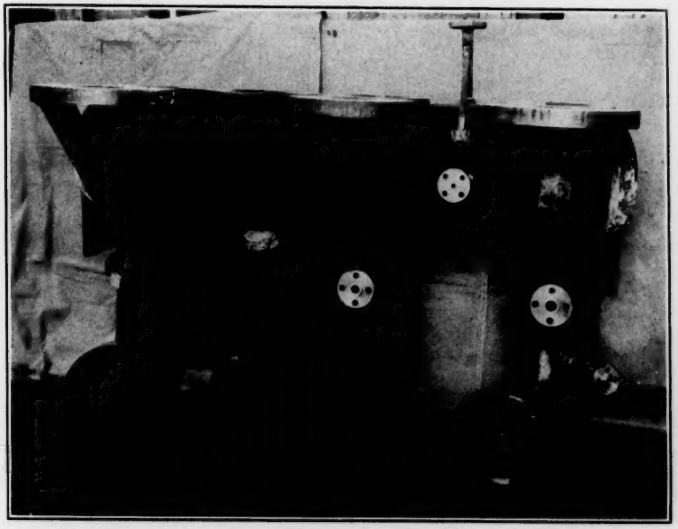

FIGURE 31—C-MO THROTTLE VALVE BODY—SHOWING WELDED ASSEMBLY.

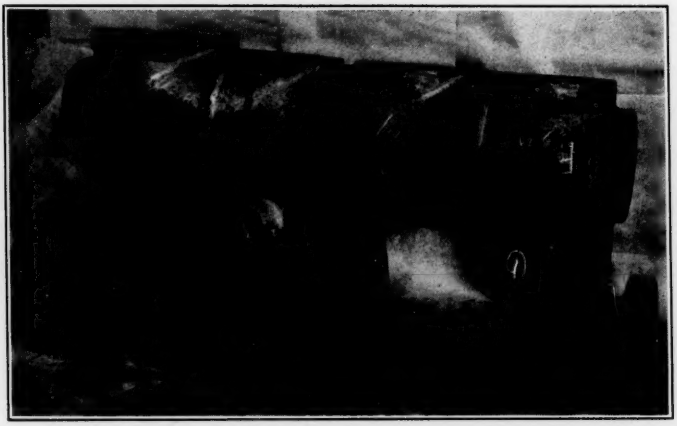

FIGURE 32—THROTTLE VALVE CASING—SHOWING CASTING WITH INTEGRALLY ATTACHED BRANCHES.

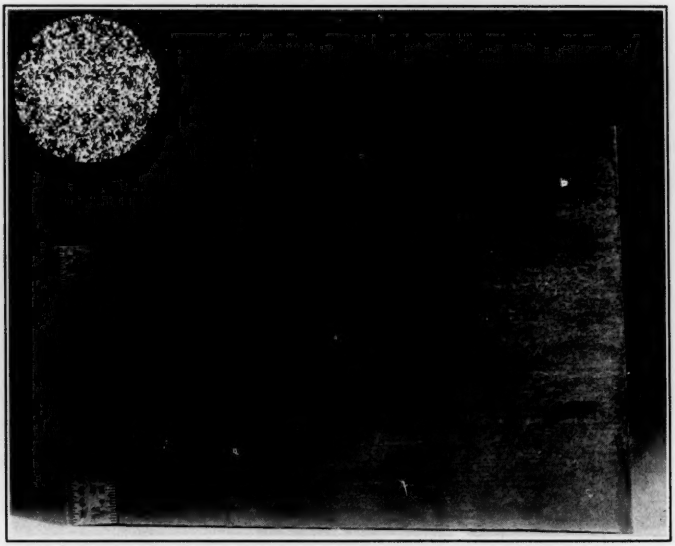

FIGURE 33—SECTION CUT FROM FACE OF HEAVY RING. NOTE DEPTH OF CHILL AND SOLIDITY OF METAL. PHOTOMICROGRAPH IS AT 100X.

(*d*) Dry molds deteriorate rapidly if allowed to set too long (24 hours and over). Their compressive and shear strengths are reduced 50 per cent or more.

Cores:

(*a*) A temperature of approximately 450 degrees F. appears to be best for baking cores.

(*b*) Spraying cores with linseed oil tends to increase their physical properties without adversely affecting their permeability.

(*c*) Washing cores with silica wash destroys their permeability.

(*d*) Prolonged exposure to air, of sandblast cores, after baking, does not damage physical properties; exposure of No. 60 oil sand cores, however, is accompanied by slight impairment of physical properties.

Summary:

The most outstanding findings discovered by the above tests are:

(*a*) Dry steel facing sands deteriorate rapidly with setting or prolonged exposure to air. This is the principal reason for the failure and burning down of the cope in anchor shank and anchor crown molds. Dry sand molds should be poured within 12 to 24 hours after drying.

(*b*) Green sand molds do not deteriorate with time, providing their surface is stabilized by torch drying before closing-up.

(*c*) Silica mold and core washes are to be used lightly and as sparingly as possible. They choke up cores and molds and thus obstruct the expulsion of whatever gases are generated within them.

(*d*) Spraying green sand molds with molasses water, and cores with linseed oil, does not harm either the physical properties or permeability.

* Table I - Steel Molding & Core Sand Mixes [1]

Part I - Steel Molding Sands

Mix No.	Composition: Sand[2] Kind	Sand[2] Amt. Lbs	Bentonite[3] Lbs	Moisture %	Surface Treatment[4]	Drying Treatment: Medium	Temp °F	Time Hrs	Aging[5] Hrs	Skin Dried[6]	Physical Properties: Perm.	Comp. psi	Shear psi	Moisture %
1a	#50	500	45	3.5	As-is	---	---	---	---	---	260.0	11.0	3.8	3.50
1b	"	"	"	"	As-is	Oven	225	1	---	---	325.0	45.7	14.1	----
1c	"	"	"	"	Sprayed	Air	Room	24	---	Yes	295.0	37.3	9.2	.70
1d	"	"	"	"	Sprayed	Air	Room	60	---	Yes	305.0	45.7	12.0	.35
1e	"	"	"	"	Sprayed	Air	Room	60	---	No	305.0	35.1	10.0	1.20
1f	"	"	"	"	As-is	Air	Room	60	---	No	320.0	25.2	8.5	.90
1g	"	"	"	"	As-is	Air	Room	120	---	No	320.0	19.4	7.5	.70
1h	"	"	"	"	Sprayed	Air	Room	120	---	Yes	290.0	47.1	12.0	.50
2a	#50 + #95	350 + 200	18	5.0	As-is	---	---	---	---	---	127.5	9.9	3.5	5.00
2b	"	"	"	"	As-is	Oven	225	1	---	---	165.0	193.5	32.0	----
2c	"	"	"	"	Washed	Oven	225	1	---	---	50.0	194.0	35.0	----
2d	"	"	"	"	As-is	Oven	600	1	---	---	179.5	194.5	30.6	----
2e	"	"	"	"	Washed	Oven	600	1	---	---	51.7	197.5	32.5	----
2f	"	"	"	"	As-is	Oven	600	3	---	---	190.0	164.5	30.3	----
2g	"	"	"	"	Washed	Oven	600	3	---	---	60.2	173.0	31.1	----
2h	"	"	"	"	As-is	M.Oven[7]	500	16	---	---	190.0	188.5	32.0	----
2i	"	"	"	"	Washed	M.Oven	500	16	---	---	73.7	197.0	32.1	----
2j	"	"	"	"	Washed	M.Oven	500	16	72	---	65.0	68.8	19.8	.35
2k	"	"	"	"	Washed	M.Oven	500	16	120	---	70.2	71.0	19.0	.55
3a	#50	500	60	5.2	As-is	---	---	---	---	---	260.0	10.0	3.5	5.20
3b	"	"	"	"	As-is	Oven	225	1	---	---	380.0	194.5	35.0	----
3c	"	"	"	"	As-is	M.Oven	475	14	---	---	385.0	194.0	33.0	----
3d	"	"	"	"	Washed	M.Oven	475	14	---	---	162.0	207.0	39.0	----
3e	"	"	"	"	Washed	M.Oven	475	14	48	---	167.0	50.6	12.0	----
4a	Heap			5.0	As-is	---	---	---	---	---	155.0	4.4	1.4	5.00
4b	"			"	As-is	Oven	225	1	---	---	200.0	78.6	24.6	----

* See Footnotes Following

4a	Heap			5.0	As-is	---	---	---	---	---	155.0	4.4	1.4	5.00
4b	"			"	As-is	Oven	225	1	---	---	200.0	78.6	24.6	----

* See Footnotes Following.

* Table I - (Part II) Core Mixes

Mix No.	Composition: Sand Kind	Sand Amt.	Mo-gul	Lin. Oil	Moisture	Surface Treatment (a)	Baking: Time	Temp.	Exposure to Air (1)	Physical Properties: Perm.	T.S.	Trans.	Flexure
	No.	Qts.	Qts	Qts.	%		Hrs.	°F.	Hours		psi	psi	psi
5a	Blast	120	2	2	7.8	As-is	4	450	---	63.0	159.5	31.8	25.3
5b	"	"	"	"	"	Sprayed	4	450	---	63.0	163.5	35.5	27.6
5c	"	"	"	"	"	Washed	4	450	---	12.0	151.2	31.5	26.0
5d	"	"	"	"	"	Sp'd & W'd	4	450	---	12.0	169.0	38.8	26.8
5e	"	"	"	"	"	Sprayed	4	450	120	62.0	164.5	34.7	34.3
5f	"	"	"	"	"	As-is	1/2	600	---	63.0	169.5	35.5	21.5
5g	"	"	"	"	"	Sprayed	1/2	600	---	62.0	154.5	48.3	27.3
5h	"	"	"	"	"	As-is	3/4	600	---	63.0	109.0	29.8	13.0
5i	"	"	"	"	"	Sprayed	3/4	600	---	63.0	122.5	21.7	13.5
6a	#60	120	---	2	7.3	As-is	3/4	450	---	170.0	125.0	30.0	11.0
7a	#60	120	2	2	7.0	As-is	4	450	---	160.0	138.0	30.8	13.1
7b	"	"	"	"	"	Sprayed	4	450	---	150.0	166.5	42.0	26.8
7c	"	"	"	"	"	Washed	4	450	---	20.0	169.0	37.0	18.8
7d	"	"	"	"	"	Sprayed	4	450	120	165.0	133.5	23.5	13.0
7e	"	"	"	"	"	As-is	1/2	600	---	143.3	187.5	22.8	43.5
7f	"	"	"	"	"	Sprayed	1/2	600	---	136.6	194.5	30.5	47.5
7g	"	"	"	"	"	As-is	3/4	600	---	145.0	163.0	29.3	38.7
7h	"	"	"	"	"	Sprayed	3/4	600	---	140.0	203.5	36.3	48.8

* See Footnotes Following.

FOOTNOTES TO TABLE I

(1) All results are expressed in A.F.A. units and are the average of at least three individual tests.

(2) The following are the uses and composition of the above sands:

Uses:

Mix No. 1 = For castings of complicated design.
Mix No. 2 = For castings of heavy section and of fairly harmonious design. Also used in large cores.
Mix No. 3 = For the making of the cope of some of the above castings.
Mix No. 4 = For backing up facing mixes #1 and #2.
Mix No. 5 = For interior cores where high green strength is required.
Mix No. 6 = For interior and exterior cores where no green strength is required.

Composition:

No.	*Name*	*A.F.A. Fineness*	*Clay*	*Moisture*
#50	Cape Henry Silica Sand.....	#40–#60	.....	3.5%
#60	Silica Sand	#60	.....	3.7%
#95	Steel Bond Sand	#96.5	20.2%	.....
.....	Steel Heap Sand	#52.4	6.8%	5.0%
.....	Used Sandblast Sand	#72.7	.....	.....
.....	Bentonite Clay	.1–5.0 microns	.....	8.0%

(3) Bentonite is a natural clay consisting principally of silica and alumina.

(4) and (8) In practice, green sand molds are sprayed with molasses water; dry molds are washed with silica wash; sandblast cores are sprayed with linseed oil; oil sand cores are sometimes washed with silica wash. The values given in Table I were obtained on specimens sprayed or washed on one side only.

	Molasses Water	*Silica Wash*
Composition:	Mixed to proportion 3 parts Foundry molasses to 50 parts water.	125.0 lbs. Silica Flour 4.5 lbs. Bentonite Clay 1.5 lbs. Mogul Binder 125.0 lbs. Water
Specific Gravity:	1.009 (60°F.)	Sp. Gr. = 1.500

(5) and (9) Aging: Time elapsing from the making of the mold to its pouring.

(6) All green sand molds are skin dried with a gas torch before closing up.

(7) M. Oven = Mold drying oven.

(Appendix)

Table II - Representative Analyses of Slag and Metal

Composition of Oxidizing (Slack) Slag
- Percent -

Period	SiO_2	CaO	MgO	MnO	FeO	Al_2O_3	P_2O_5	CaS	CaC_2	CaF_2	Ignition Loss
Beginning	29.62	17.26	19.85	13.30	13.80	5.24	.06	.09	.10	--	None
Ending	29.67	19.44	22.22	12.15	9.62	4.81	.04	.11	.06	--	None

Composition of Refining (White) Slag

Beginning	12.62	55.70	8.69	.77	.62	8.90	--	.39	1.66	9.06	1.15
Ending	19.34	46.44	15.84	.34	.71	13.10*	--	.57	.22	4.86	0.00

Analyses of Three Heats, Oxidized to Various Degrees

Period	C.	Mn.	P.	S.	Si.	Ni.
(Heat 404)						
After melting (1st prelim.)	.20					
After melting (2nd prelim.)	--	.29	.025	.060	.05	.23
Middle of refining (3rd prelim.)	.23	.47	---	---	--	--
Final analysis	.23	.59	.020	.020	.32	.22
(Heat 422)						
After melting (1st prelim.)	.06					
After melting (2nd prelim.)	--	.12	.011	.050	.01	.31
Middle of refining (3rd prelim.)	.14	.56	---	---	--	--
Final analysis	.24	.58	.020	.020	.29	.25
(Heat 411)						
After melting (1st prelim.)	.01					
After melting (2nd prelim.)	--	.08	.025	.040	.01	.10
Middle of refining (3rd prelim.)	.14	.51	---	---	--	--
Final analysis	.20	.59	.020	.020	.32	.08

Approximate Amount of Flux Materials Used in Making Above Slags

Oxidizing Slag		Refining Slag(1)			
Plate scrap	13,500 lbs.	Lime	250 lbs.	50%Fe-Si	50 lbs.
Foundry scrap	8,500 lbs.	Cement	94 lbs.	85%Fe-Mn	170 lbs.
Iron ore	25/30 lbs.	Fluorspar	90 lbs.	70%Fe-Ti	25 lbs.
Limestone	250 lbs.	Coke	15/30 lbs.	Al.chips	20 lbs.
Lime	250 lbs.			Pig iron	300 lbs.
CaO/SiO_2 Ratio	4.0 Approx.				

*This figure represents the sum of Al_2O_3 and TiO_2. From all indications the TiO_2 appears to be less than 1.0%.

(1) .15% Si is added before removing 1st slag. Immediately after slagging off, balance of Fe-Si and Fe-Mn is added. Final additions are: .05% Si; Fe-Ti; and calcium silicide.

(Appendix)

Table III - Physical Properties on a 20,000-Pound Anchor Crown (After Standard Annealing Treatment)

Location of Specimen	T.S. psi	Y.P.[2] psi	% Elong. in 2".	% R.A.	Izod Impact[3] Ft. Lbs.		
Coupon[1]	67,500	41,250	34.0	54.5	---	---	---
Outside[4]	65,500	37,250	28.0	39.1	36.0	37.5	41.5
Midway	66,250	40,000	20.0	25.8	34.0	33.0	34.0
Center	63,250	40,000	17.0	24.1	39.5	25.0	35.5
	Trepanned Specimens Re-Annealed at 1650oF for 2Hrs.						
Outside	68,500	45,000	35.0	54.4	42.5	47.5	41.0
Center	68,750	45,750	20.0	26.8	45.0	41.0	50.5

Transmissibility of Impact Loads at 80° and 32°F.[5]

Location	Single Width (10mm)	Double Width (20mm)	Temp. of Test	Heat Treatment
Outside	23.0	42.5	80°F	Standard Anneal.
Outside	26.0	50.0	80°F	Trepanned & Re-Annealed at 1650°F for 2hrs.
Midway	13.5	15.0	32°F[6]	Standard Anneal.
Midway	18.5	42.5	32°F	Trepanned & Re-Annealed at 1650°F for 2hrs.

(1) Coupon attached to underside of fluke.
(2) Divider Method.
(3) 10mm square, V notch, 120 ft-lb setting.
(4) Specimens taken from failed anchor crown. See Fig. 11.
(5) Charpy type impact specimens, one 10mm square and the other 10mm thick by 20mm wide. Hammer let fall from 220 ft-lb setting.
(6) Specimens were held for one hour on melting ice, then tested.
Note: Dimensions of section tested = 9"thick by 12" wide by 30" long.

Bibliography.

(1) C. W. Briggs, "The Strength and Ductility of Steel Castings at Hot Tearing Temperatures," N. R. L. Report No. M-1479, 22 Sept. '38.

(2) Albert P. Gagnebin, "The Effect of Deoxidation Treatments on the Ductility of Cast Steels," Transactions of the A. F. A., Vol. XLVI, No. 1, Sept., 1938.

(3) Charles McKnight, Jr., Discussion on paper by F. T. Sisco, "Electric Furnace Steel," A. S. S. T., Vol. 8, Dec., 1925.

(4) C. W. Briggs and R. A. Gezelius, "Studies on Solidification and Contraction in Steel Castings—III—The Rate of Skin Formation," A. F. A. Transactions, 1935.

(5) A. Heuvers, "Was hat der Stahlgieber dem Konstruktem uber Lunker-und Ribbildung zu sagen?" Stahl und Eisen, 1929, No. 35.

A NEW SPECTROGRAPH TESTING TECHNIQUE, ESTABLISHED AT PEARL HARBOR NAVY YARD.

By W. H. Hammond.*

The Industrial Department of the Pearl Harbor Navy Yard has recently installed a grating spectrograph in the general testing laboratory to be used in increasing the technical efficiency of ship overhaul work.

The Pearl Harbor spectrograph is of a relatively new type to be manufactured for general industrial analysis. There are features in its installation of original design. The uses to which such a piece of equipment may be put in a purely repair and maintenance yard may not be self-apparent. Therefore, its description will be of interest as an adjunct to the control and inspection of materials.

Spectrographic analysis is a branch of microchemical analysis, that is, it gives information as to what elements are present, using a small sample weighed in milligrams. It does not displace older types of chemical analysis, but it does offer very definite advantages where it can be applied. These advantages can be summarized as follows: (1) A very small sample is required. (2) Test is made quickly. (3) Operating cost is low. (4) In some cases, it gives results which cannot be secured at all by older methods. (5) In other cases, it supplements older methods. (6) Probably its chief advantage, from the standpoint of an executive officer or civilian head of a laboratory, is that it puts the results into a permanent, record form, which can be checked by any other man, technically qualified to read the spectrographical pictures. In other words, instead of a set of figures, referring to those ingredients which the laboratory was told to look for, the spectroscope gives a picture which shows all the lines of all the elements present, within the limits of the instrument and technique, including those elements which no one would have thought to look for.

* Head of Pearl Harbor Navy Yard Testing Laboratory.

To be of much value in general metal analysis, a spectrograph must be able to work in the ultra violet; in other words, in the range below visibility, or below 4000 Angstroms, where only a photographic film can pick up the lines. The range 4600-2300 A. degrees gives lines of about 70 elements. Working this range are two American-made spectrographs, one based on a quartz prism, such as the one at Philadelphia, and the other, such as ours, using a concave, reflecting metal grating, ruled with 48,000 one-inch lines, over a two-inch length. This latter type diffracts the mixed light vibration, emitted by the glowing atoms in the arc or spark, by a process, much like that by which a pool of oil on a wet street gives interference colors. The advantages claimed for this grating type of spectrograph may be summarized as high resolution and wide dispersion, linear dispersion, and ease of operation. Resolution is the ability of the instrument to focus the lines so clearly upon a photographic plate that lines a few tenths of an Angstrom apart can be separated with certainty. Our instrument, for example, shows the iron group, Angstroms 3099.90-3099.97, 3100.31 and 3100.67 as a clearly marked triplet, the first two lines (with the usual working adjustments) appearing as one, the third and fourth lines well separated (our resolution can be checked by the reader, by a reference to Plate III. The three lines in the iron-manganese triplet showing are 4030.76, 4033.07 and 4034.49 Angstroms, respectively). Contributing to the resolution is the dispersion of the instrument, or the distance by which the lines are separated on the film. The rated dispersion of this instrument is 7 A. degrees per millimeter on the film and about 0.15 A. degree per millimeter on the screen, when projected. One advantage of the grating spectrograph, in our opinion, is that it gives a linear, instead of a logarithmic dispersion. Whatever the exact distance per Angstrom, as measured by a rule, at one end of the film, after the adjustments have been fixed and locked, we can depend upon our measurements at any place in the film to be the same. In a prism instrument, the lines are " bunched together " at the high Angstrom end. Ease of operation of this instrument is obtained by incorporating in the projector, a glass plate upon which is ruled (1) an Angstrom scale, (2) an iron, reference spectrum, and (3) the most persistent lines of such elements as the manufacturer thinks

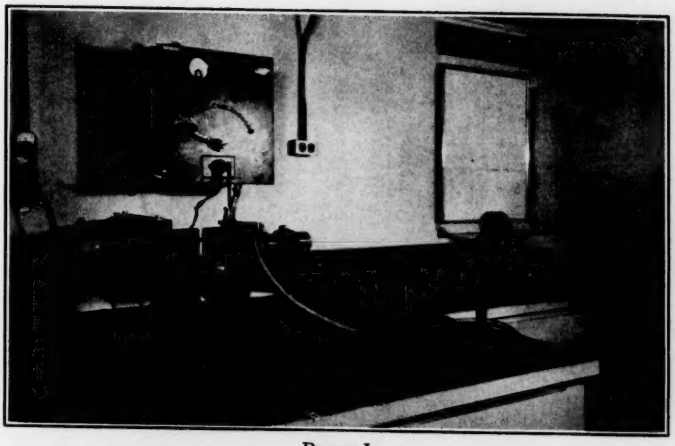

PLATE I.

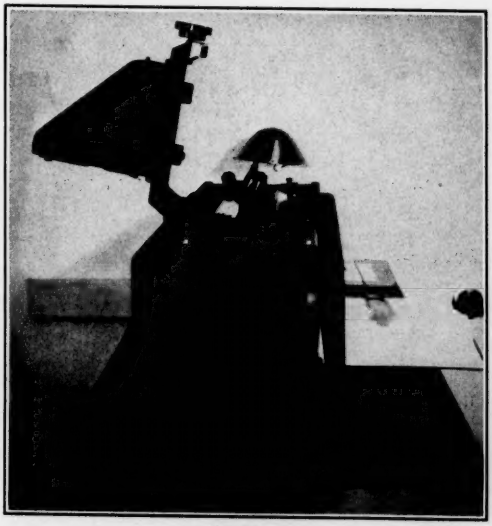

PLATE II.

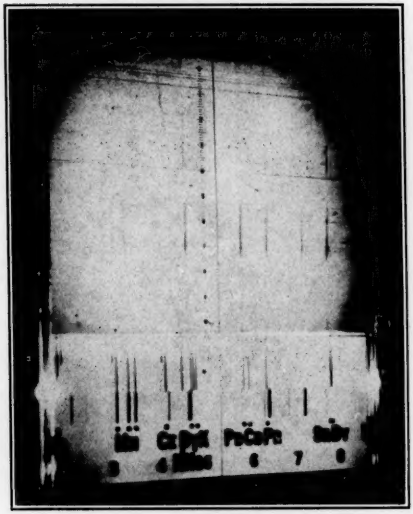

PLATE III.

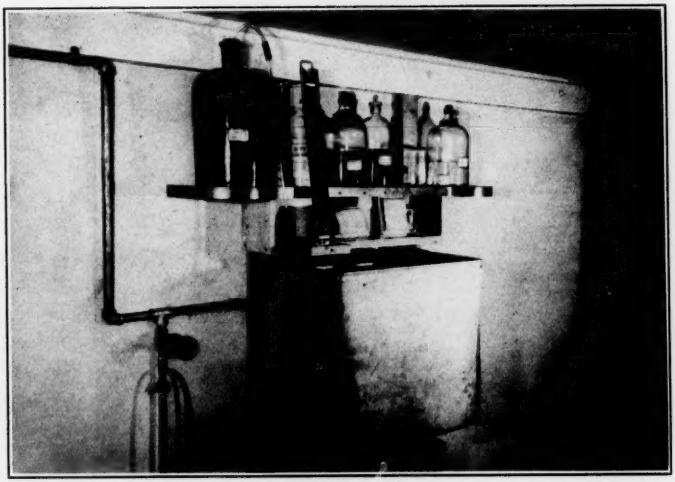

PLATE IV.

will be useful to the operator. On Plate III (q.v.), the projected image of the glass plate shows on the lower portion of the screen. To make an analysis, the analyst runs the images of sample film and glass plate together across the screen and reads the identity of any unusual line by reference to the scales on the plate below.

The general construction of this instrument can be described briefly, omitting features already discussed. The heart of the apparatus is the grating, a block of non-corrodable metal (usually speculum, an alloy of copper and tin) which is ground slightly concave, engine-ruled with 48,000 lines to the inch, over two square inches in the center of its surface, and then made highly reflecting to ultra-violet light by having a mirror-like aluminum film deposited on its face, by the same method as is used in making mirrors for astronomical telescopes. This grating is mounted at one end of the diameter of a semi-circular aluminum cast base, of the type known as the "Rowland Circle." At the other end of the diameter is mounted the camera, a box without lenses, mounted on a ratchet so that a maximum of about ten samples can be photographed, side by side, on one 13-inch section of film. The peripheral section of the circle is bored at two locations for the mounting tube of the slit and quartz condensing lens, which focuses the image of the slit upon the grating. The location to the right of the operating position gives the visible spectrum, range 4600-6800 A.; to the left, gives the more useful violet-ultra-violet range, 4600-2400 A. Behind the slit is mounted a cast aluminum arc housing, containing a moveable table bored for eight electrodes with samples. When a film is exposed, developed and dried (or partly dried), the sample spectra are analyzed by projection, using a special screen and projector.

This instrument and features of our assembly are illustrated in the accompanying pictures. Because the instrument is not enclosed, it must be set up in a room which can be made light-tight. We have made a special room for it, about 10 feet $\times$ 10 feet, with a small jog into which the door admits. Plate V shows the floor plan. Plate I shows the spectroscope. It is mounted on a table, designed with an extension, as shown, to take the outer leg of the Rowland Circle. Above, mounted on the side wall, is a rheostat with 17 live taps to control the amperage (actually only enough

steps to give currents of 5.7 and 10 amperes would probably be sufficient). An ammeter and, ordinarily, a voltmeter is also mounted on the panel (when these pictures were taken our voltmeter was undergoing repairs). Our line voltage can be varied in steps up to a maximum of 340. A small, hooded light, run by a flashlight battery and controlled by a small switch to the lower

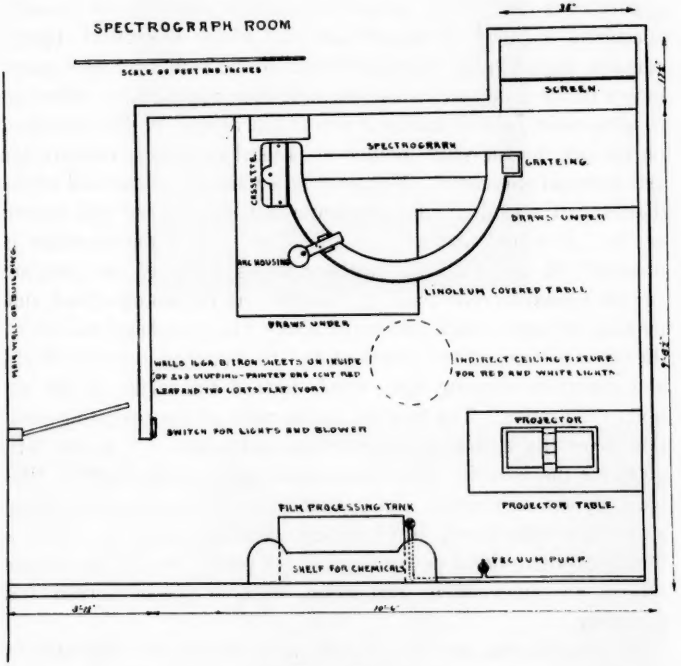

PLATE V.

left, keeps the dial of the ammeter illuminated during a run. There is a distant station, stop-go switch mounted on the wall to the far left which controls the D. C. generator on the floor below. A rubber tube goes from the top of the arc housing to a small, water-operated suction pump, which itself is connected to the water and sewer lines. Another rubber hose is shown in Plate I connecting a

compressed-air tap with the bottom of the housing. We find that the lines photograph much more sharply, and the lens is less fogged, if the mist of metallic oxides which forms during a run is constantly swept clear. There is a trap, made out of a glass bottle and glass wool, under the table in the suction line, to receive the oxides. Ventilation for the room is by a regular motor-driven ventilator, augmented by a " stir-up " fan.

Plate I shows the grating housing at the far end, with a glimpse of the grating through the front aperture, and the screen, mounted in the wall behind. We mounted the screen as shown because we plan eventually to mount a photoelectric light "pick-up" cell, of the type used in Navy sound track, movie projectors, in a slit-housing behind the screen, with an amplifying train, which a radio electrician on the Yard is now working out, to serve as densitometer, and accurate means of making quantitative analysis, based on relative density of the lines.

Plate III shows a photograph of the screen as actually seen during an analysis. We were examining a film, taken of several samples of Navy Compo-W babbitt, mounted for purpose of analysis in graphite electrodes. The upper part of the screen shows parts of four sample spectra. The lines were very clean cut on the screen; they have become somewhat blurred by halation in reproducing. Lines showing are iron and manganese impurity lines from the electrode, of no significance, in this analysis, and one lead line, immediately above " Pb " and accompanying line on the image of the glass reference plate, which is of great significance. Counting from the top, No. 1 spectra was a blank run on the electrode; No. 2 was of a sample containing 0.17 per cent lead (by ordinary, check chemical analysis); No. 3 contained 1.02 per cent lead; No. 4 contained 0.53 per cent lead. Of these samples, No. 2 was the only one complying with ND specification 46-M-2e, with respect to lead. A simple comparison of the density of the lines, by eye, was sufficient in this case to pick out the only pot of remelt which could be poured.

Plate II shows the projector, with top up, ready to receive a film. Behind is a hooded light, over the analyst's data board, with switch.

Plate IV shows the apparatus which Mr. Loveland, one of the civilian supervisors on this Yard, designed to make quick develop-

ments of the exposed film. Since spectroscopy is a speed type of analysis, any corners that can be cut at any step in the complete process make a departure of general value. With the room in darkness, if using panchromatic movie film, or illuminated by faint red light, if using the preferable orthochromatic, the exposed section of film is removed from the camera and snapped into the metal holder, shown standing against the developer cans in the picture. Film and holder are then lowered into the narrow, perpendicular tank, whose top just shows to the left above the top of the water bath. The hinged wooden cover is then lowered, and the light can be turned on to develop in D-72 (Eastman) for 3 minutes. Since one filling of developer should not be used more than once, the tank is made to fit the holder very closely to avoid waste of solution. The other two tanks, shown, are for chrome alum hardener, and for fixer. These tanks are placed in the water bath for the sake of temperature control. Plate VI shows the details of these tanks.

The level of the water is kept constant by an overflow, venting into the long trough into which the solution tanks also drain by

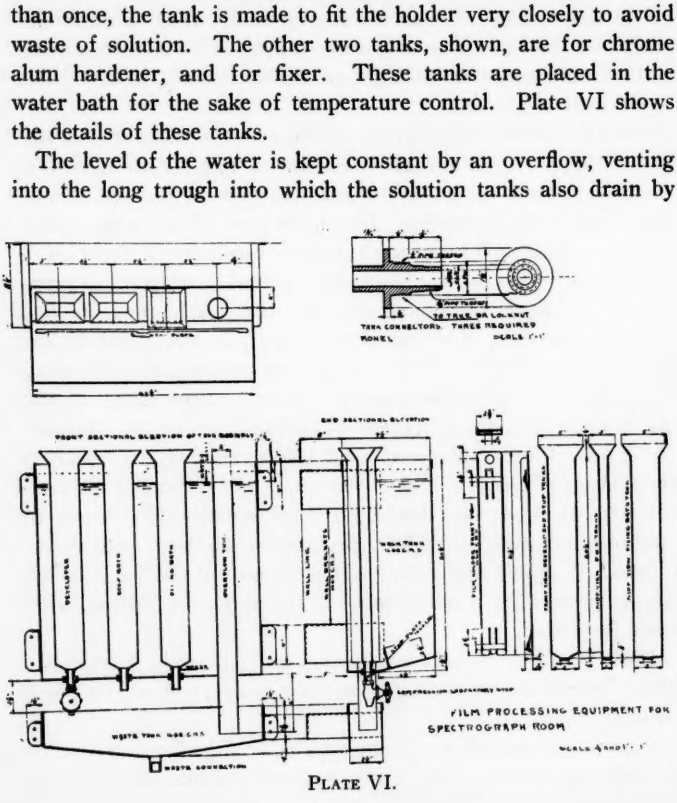

PLATE VI.

means of faucets. The sheet metal is Navy CRS.; the cocks are ordinary stock issue. If and when the solutions corrode them out, we will simply replace them.

After 3 minutes in the developer, the film holder is placed 1 minute in the hardener, which prepares the gelatine for the later rough treatment. The next operation is 6-8 minutes in the fixer, or long enough to "clear." After about 45 seconds in the fixer the film can be examined by white light. When the milky deposit of silver bromide has been dissolved from the film, it is washed for about one minute in running water.

A piece of chamois skin is then wet to soften its texture, wrung out, the film removed from the holder, and then the film, held by one end, is wiped dry of superficial moisture with the soft, damp chamois. The hardened film receives no injury. In case of emergency, the semi-dry film can now be placed in the projector and examined immediately. It can be read more accurately, if allowed to dry in front of the fan for 5-10 minutes. These films are only semi-permanent when rushed through in this way, but are perfectly satisfactory for most analyses.

The total steps in an analysis, with the estimated timing, are as follows:

A—Preparation of sample

1. Taking hack-saw sawings of a metal, or
2. Fine drillings, or
3. Removing a chip from a hardened steel by carborundum cutting wheel, or
4. Impregnation of drop of liquid sample into a drilled graphite electrode, or
5. Impregnation of a few milligrams of a dry, powdered sample into a drilled, graphite electrode.

Aa—This step takes from 5-30 minutes, depending on type of sample received.

B—Arcing of sample in instrument, in duplicate, with blank and two controls (samples of known composition, with impurities in same range as expected in unknown, preferably one at bottom and one at top of range).

Bb—Estimate, 30-120 seconds for arcing, depending on type of sample.

C—Development of film.

Cc—7-10 minutes. We have rushed one through in 5.

D—Analyzing the film in the projector.

1. Locating lines due to impurities, or alloy constituents.
2. Estimating intensity.
3. Recording on data board.

Dd—Obviously the speed of this step depends on the ability of the laboratorian, and his experience with the particular type of sample. On routine checking a man should complete the analysis of a single sample in 1-2 minutes. In examining a film, filled to capacity with spectra of a group of samples of the same type, 1 minute per sample should be time enough.

This timing is the most rapid developed yet by any general method of chemical analysis, for miscellaneous samples.

Questions will be raised as to the accuracy to be expected and the applicability of spectral analysis to the general run of Navy Yard samples. "Is accuracy lost, in gaining speed?" We stated originally that this type of analysis would not displace the regular use of chemical reagents. "But, what samples can be analyzed spectroscopically?" The answer to the first question is that with proper equipment, steady line voltage, a good densitometer for accurately measuring the density of the spectral lines, and using the new type of "boiler" electrode developed by Hasler and Lindhurst, an experienced man should secure an accuracy of 2 per cent on certain elements in the range 0.001-0.01 per cent, 5-10 per cent in the range 0.01-0.1 per cent and 10-20 per cent in the range 0.1-1 per cent. Above 1 per cent, the method is of chief value in making a complete qualitative analysis, to serve as a guide to the head chemist in selecting applicable methods for a complete quantitative analyses by usual means. In other words, a lead impurity in high tin babbitt, of the order of 0.5 per cent should be reported by spectroscopy as not below 0.4 per cent and not above 0.6 per cent, at maximum possible error. However, an operator, with experience in checking pots of babbitt should cut this error down. The applicability of spectroscopic analysis, at least with apparatus such as ours, is, roughly speaking, to metallic, alkali and alkaline earth elements. The gases, phosphorus, carbon, sulphur, and or-

ganic complexes are typical ingredients of many samples no information on which can be gained from a spectral analysis.

Within these limitations, spectroscopy is a very valuable tool. An operator can sort alloy steels from plain carbon bars, for example, and give in most cases a sufficiently accurate quantitative report, considerably faster than the tool room helper can saw off and bring in the samples. In many cases of mixed steels in the machine and forge shops, a spectroscopist can pick out the steel called for in the plan and phone in his report before the helper who brought the sample can walk back. Foundry scrap can be arced rapidly and reported on for impurities cheaply. Since eight samples, with controls, can be placed on one film, spectroscopy is an ideal method for handling large pieces of scrap, individually, which would have to be composited into one sample for a regular analysis. Because spectroscopy is a microanalysis, milligram samples can be picked out at the exact location of trouble in metal sections, such as porous places in castings, pitted locations in corroded sheets or sources of excessive gassing in lead-acid battery plates. This technique shows up segregation. In many cases, the five-gram composite sample which would be required to show up a 0.1-gram impurity in ordinary macro-analysis could be split up into 250 20-milligram samples, each of which would be sufficient for a complete spectral analysis. We found a segregation of aluminum oxide in this way which was making porous spots in gun metal pressure valves. Welding fluxes of unknown composition can profitably be given a qualitative run on the spectroscope. Since the modern alloy steel may, and does commonly contain ingredients, such as columbium, cobalt and zirconium, which very few analysts would think to look for, all samples of alloy steel, of unknown origin, should probably be given a short, routine analysis on the spectrograph, if for no other reason than to guard against an unauthorized composition slipping into production. Some alloys, such as brasses and bronzes, are commonly analyzed, with zinc (or some other metal) reported "by difference." Such a procedure is admittedly unscientific; however, we believe that it becomes rigorous if on the report is added "other elements—no more than spectrographic traces." There are at least three metals, which Bureau specifications either require a Navy chemist to report on

in battery acids, or else commonly occur in old acid, namely, tungsten, platinum and zinc. The first two cannot be determined at all, by ordinary means, in the size sample which can be spared from the battery for a routine report; the third cannot be determined accurately, by a practicable colorimetric analysis, in the presence of the maximum amount iron allowed. We are hoping to avoid the difficulties by spectroscopy. Minute samples of deposits, sediments and scales, representing scrapings, are commonly received at the laboratory, insufficient in bulk for anything except microscopic inspection; many of these samples are sufficient for a satisfactory spectroscopic analysis, which would form the basis for a report on the source of the trouble. As mentioned before, one more great advantage of a spectroscopic analysis is that it puts the evidence into photographic form, which the officer and civilian head of the laboratory can study with the laboratorian. In other words, spectroscopy, where it applies, puts chemical analysis where metallographic analysis is now, into a graphic form where the men whose signatures appear on the report can "go back of the figures."

Mention was made above to our use of the new "boiler" electrode. Using the old open electrode, spectroscopy with the arc at 220-250 volts was less dependable in most cases than with the spark at 10,000-20,000 volts. We have found that use of the enclosed, capped electrode, which was introduced a few months ago, has put analysis with the lower voltage upon about the same stable basis as any form of microanalysis.

The author would like to express his appreciation at this point to Mr. J. E. McCambridge, Metallurgist, and Mr. J. Sherman, Spectroscopist, at the Philadelphia Navy Yard, and Mr. G. F. Lundell, Chemist, and Mr. B. F. Scriber, Spectroscopist, at the Bureau of Standards, for assistance given to him personally during the preliminary investigation which resulted in the purchase of a grating spectrograph.

Amongst the many recent publications on spectroscopic analysis, a few might be cited which would be of particular interest to an officer approaching the subject from the standpoint of typical Naval problems. These will be listed:

(1) "The Spectrographic Analysis of Certain Materials to Determine Their Conformity to Specifications," by Dr. Jacob Sher-

man and Mr. W. J. Jeffries, this JOURNAL, Vol. 50, No. 1, of February, 1938.

(2) "Spectrography for Rapid Industrial Application," Metal Progress, XXX, 3, p. 57 (article by Hasler and Lindhurst, describing their instrument in fairly full detail).

(3) Different advertising publications of Hasler and Lindhurst, entitled "Spectro-Chemical advances," especially No. 1, giving the plan and dimensions of the boiler electrode, and No. 2, describing their densitometer. Published by Applied Research Laboratories, 1208 San Julian St., Los Angeles, California (free).

(4) "Rotating Sector for Quantitative Analytical Spectroscopy," Rev. Sci. Instruments, VII, (1936), p. 137 (a description of one method of quantitative analysis, which has proved disappointing at this Yard. Of interest, in a complete review of the subject).

(5) "Practical Possibilities in Spectrographic Analysis," Metals and Alloys, November (1936), p. 290. (An excellent, general article by Prof. George R. Harrison of M. I. T. on instruments and technique. Discusses possibility of determining carbon, sulphur and selenium by spectroscopy.)

(6) "Spectrographic Analysis," Progress Reports, Metallurgical Division, Bureau of Mines, RI 3370, February (1938). (Use of spectroscope in ore analysis; extensive bibliography.)

(7) "Twenty-five Determinations on Cast Iron in Twenty-five Minutes," Iron Age, 139, 20, p. 25. (An article by F. J. Oliver, Associate Editor of Iron Age, upon the application of prism spectrograph by Professors Vincent and Sawyer, of the University of Michigan, to running fast analysis on alloy cast iron heats in the foundry.)

(8) "Symposium on Spectrographic Analysis," A. S. T. M. Reprint, Vol. XXXV, Pt. II (1935). (Discussion under auspices of the American Society for Testing Materials; somewhat obsolete at present.)

(9) A. S. T. M. Tentative Methods (1936).

E 25-35-T, "Spectrographic Method for Pig Lead."

E 26-35-T, "Spectrographic Method for Spelter."

E 27-35-T, "Spectrographic Method for Zinc."

ALLOY DIE CASTING.

(10) "Introduction to Atomic Spectra" (book), by H. E. White (University of California, Berkeley, California). (Test on the theory and mathematics of spectral analysis. Discusses at length the physics of the atoms, and the relation of spectral lines to atomic structure.)

CHARACTERISTICS OF WELDING ARCS AND WELDING SET CIRCUITS.

By Wilmer E. Stine.*

A fluctuating electric process accompanies the deposition of weld metal by electric arc. The success of the process depends upon the manner in which the electric circuit responds to transitory influences in the arc. The author explains the several influences and derives the electrical qualities that maintain a stable and efficient welding arc.

The highest temperatures in our world today are obtained by means of an electric arc. Because of the inherently high temperature of an electric arc its characteristics can not be readily observed. Like many other things in the physical world, we obtain our knowledge of arc characteristics by making observations as to the method of establishment, and the behavior under certain controlled conditions. By gaining more knowledge as to the characteristics of the arc we can better prescribe the desirable characteristics of electric welding sets.

In this discussion an arc will be considered to be the mechanism by which electric current is conducted between two solid conductors through a gaseous mixture at atmospheric pressure.

Observations of simple arcs such as those between carbon electrodes or between iron electrodes has revealed that there is a certain minimum voltage necessary to maintain an electric arc between solid conductors and that this voltage varies for different materials. This will be designated as the voltage necessary to maintain an arc of infinitesimal length. For iron electrodes minimum arc voltage is approximately twelve volts. It has also been observed that most of the potential drop in a simple arc takes place at or near the

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cathode (negative electrode), that there is some potential drop across the arc stream and probably some potential drop at the anode (positive electrode).

The current through the arc is conducted by electrons traveling from the negative electrode toward the positive electrode and also positive ions traveling from the positive toward the negative electrode. It is generally assumed that most of the current is conducted by means of the electrons. It is therefore necessary that large numbers of electrons become detached from the negative electrode in order that they may travel through the arc to the positive electrode and thus maintain the flow of current.

There seems to be no single phenomenon that adequately explains how sufficient electrons are pulled out of the negative electrode to carry the current. It is generally accepted, however, that a combination of high temperature and relatively high potential gradient at the cathode spot furnishes a combination of conditions which succeed in detaching and pulling out the necessary electrons for carrying the welding current. All of the electrons detached from the cathode may not reach the anode before recombining with ions to form atoms and molecules, taking the place of electrons which have become detached from atoms by the process of high temperature and collision with electrons in the arc stream.

It may seem contradictory to say that in simple arcs most of the voltage drop occurs at or near the negative electrode, but that most of the heat occurs at the positive electrode. If we assume, however, that the electrical potential is instrumental in detaching and imparting to the electrons a relatively high velocity and they have relatively free passage through an atmosphere that is easy to ionize, they will lose only part of their energy in collisions with atoms in the arc stream and will strike the positive electrode with relatively high velocity and give up their energy in the form of heat as they strike the positive electrode and raise its temperature. It is also probable that some of the energy used in ionization is converted into heat at the point of recombination.

Why Use Reversed Polarity (Electrode Positive).

During the early stages of electric arc welding when simple iron or carbon arcs were used, it was generally true that most of the

heat appeared at the positive electrode, and since it is generally desirable that most of the heat appear in the work, it became the normal practice to make the electrode negative polarity. This has been designated as normal or straight polarity.

The introduction of covered electrodes changed the situation. Covered electrodes introduce a gaseous atmosphere that is hard to ionize. This atmosphere contains hydrogen and in many cases organic compounds. They require from five to ten volts higher electric potential to maintain an arc of normal length. There is more interference to the flight of the electrons through the arc, so that the relative velocity of the electrons is probably slower. The electrons lose their energy in collision with the rugged molecules and atoms near the cathode, as a result of which most of the heat now appears at the cathode. Under these conditions we generally reverse the polarity of the electrode, because, except when welding light-gauged metal, we generally want most of the heat to appear in the work. Most of our so-called " all position " electrodes come under this classification and are called reversed polarity electrodes, indicating that the electrode should be positive. This type of electrode is extensively used and it is therefore no longer generally true in electric arc welding that most of the heat appears at the positive electrode.

Electrode Current.

It has been found under practical welding conditions that the best results for certain types of welds are obtained over a limited range in current for each size of electrode. It is therefore desirable that the welding circuit have variable voltage characteristics so that throughout the arc voltage range the current varies only over a limited range.

Arc Stability.

Temperature plays a major role in the process of ionization and the maintenance of ionization throughout the arc stream. It is therefore important that, if a transient condition occurs which tends to reduce the temperature or increase the rate of recombination of the ions, the electric circuit respond in a manner that will make more heat available to prevent a further fall of temperature

and raise the temperature as necessary to maintain equilibrium conditions. Since a decrease in ionization in the arc stream results in increased electric resistance, it is necessary for arc stability that the electric circuit be so arranged that an increase in arc resistance results in sufficient increase in voltage that the watts and heat of the arc be increased. Therefore, for arc stability, it is necessary that the watts (heat) under transient conditions vary inversely with the arc resistance and consequently arc voltage.

It should be borne in mind that the changes in the rate of ionization and of recombination of ions take place very rapidly and therefore that the transient characteristics of the electric circuit which supplies energy to the electric arc are of major importance.

General Requirements for Welding Circuits.

Under some welding conditions we do not have an arc at all times. Drops of molten metal short circuit the electrode for a short period of time, during which the voltage drops below that which will maintain an arc and the arc ceases to exist. When the drop of molten metal breaks loose from the electrode a new arc is established. This is illustrated in Figure 1, which is an oscillograph record of the current and arc voltage under normal welding conditions when using a light-coated electrode. In this case the arc is relatively short and the globules of molten metal frequently bridge the gap between the electrode and the work. It will be noted that the period of the short circuits varies from approximately one-sixtieth of a second (as indicated by the 60-cycle timing record) to one-twentieth of a second (three cycles), and that between the short circuited periods the arc resistance rapidly changes, causing corresponding changes in arc voltage and arc current. It is, therefore, desirable that in practical welding circuits we not only have conditions suitable for maintaining an arc, but that the current and heat conditions during the short circuited period are also satisfactory. An arc welding circuit, therefore, must have not only characteristics for maintaining arc stability, but also must have desirable characteristics during transient short circuits.

Various standards of performance under specified transient conditions have been proposed for determining by laboratory tests the ability of welding sets to give satisfactory performance under the rapidly changing conditions experienced in welding.

60~
RATING - 200 Amps
SETTING - 200 Amps, full field, full reactance
TESTED Normal Welding
75
50
25
0
VOLTS
300
400
300
200
100
0
A.W.S.
A.E. - Arc broken intentionally

FIGURE 1.

The standards of the American Institute of Electrical Engineering in effect ten or twelve years ago established a minimum time of recovery of the welding current under certain specified loads of the welding set. The set was to be connected to a resistance load equal to the normal load and one-half of that resistance short circuited. The short circuit was then suddenly removed and the time required for the current to recover to within five per cent of the normal load was specified.

In 1929 the Navy Department established a standard of time of recovery from short circuit to normal load and also limited the permissible amount that the current could fall below normal during this transient condition. With minor modifications, this standard of performance is required by the present Navy Department specifications.

The present American Institute of Electrical Engineering's standards defines a standard method of measuring time of recovery of voltage from short circuit to open circuit which is based upon time for voltage to reach fifty per cent of the open circuit voltage. This standard is based upon recovery of voltage under no load conditions and differs from the requirement of the Navy Department specifications which are based upon time of recovery of voltage under full load conditions. The time for recovery permitted under Navy Department specifications depends upon how low the current drops when the short circuit is opened. Permissible values are tabulated below:

Minimum Current, Per Cent of Normal.	*Time of Recovery to Within 5 Per Cent of Normal.* Seconds
60	0.20
65	0.30
70	0.45
75	0.70
80	1.00
85	1.4
90	3.00

It can be shown that there is no one test that will determine satisfactorily the performance of welding sets under actual weld-

ing conditions. A careful analysis of various types of welding circuits and the nature of their short-comings gives clues as to methods for improvement and standards for comparison.

The simplest and most easily analyzed electric arc welding circuit is shown in Figure 2, which consists of a storage battery, B; a resistor, R; an electrode, E, and the work, W. If the battery voltage is forty volts and the resistor has been adjusted so that

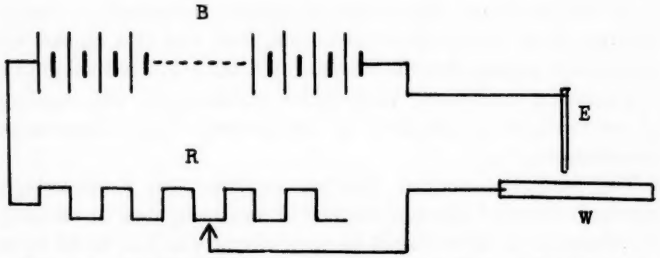


FIGURE 2.—ARC WELDING CIRCUIT CONSISTING OF STORAGE BATTERY AND EXTERNAL RESISTOR.

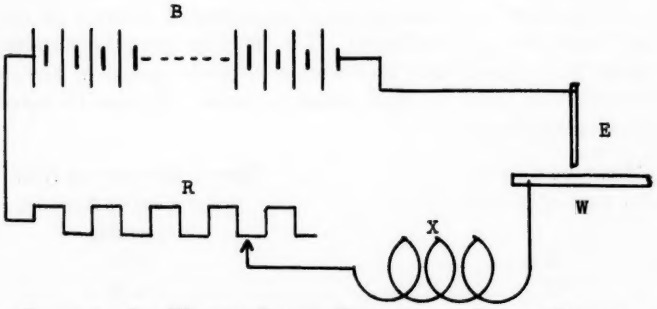


FIGURE 5.—ARC WELDING CIRCUIT CONSISTING OF STORAGE BATTERY, EXTERNAL RESISTOR AND REACTOR.

when using a ⅛-inch covered electrode with a normal voltage of twenty-five the welding current will be 100 amperes, the characteristic curves will be as shown in Figure 3. Curve A in Figure 3 represents the volt-ampere characteristic under static conditions. Curve B represents the watts output of such a circuit under static

conditions. Since there is no reactance in the circuit and no time constant in the battery, the characteristics under transient or rapidly changing conditions of arc resistance exactly coincide with the static characteristics.

When the circuit whose characteristics are as illustrated in Figure 3 is tested against the American Institute of Electrical Engineering's standards for time recovery it is found that it recovers

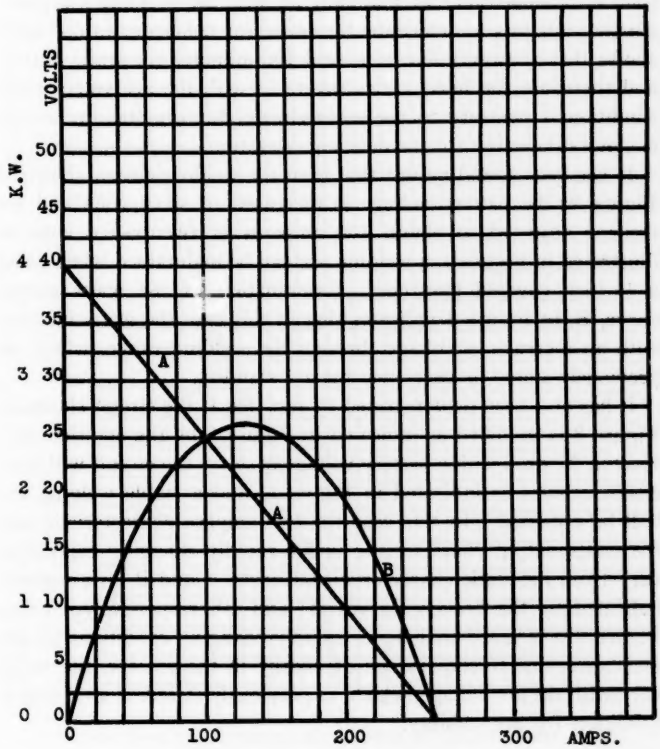


FIGURE 3.—CHARACTERISTIC CURVES FOR 40-VOLT BATTERY WITH EXTERNAL RESISTOR.
CURVE A—VOLT-AMPERE CURVE.
CURVE B—WATTS OUTPUT CURVE.

instantly to 100 per cent of the open circuit voltage and therefore fully meets the requirements.

When tested to determine compliance with the Navy Department requirements for recovery under load conditions, it is found that it recovers instantly to normal and therefore meets the specified requirements. When an effort is made to use this circuit under normal welding conditions, with a ⅛-inch electrode which requires approximately twenty-five volts at the arc, it has been determined that it is impossible to maintain an arc for welding purposes. Further analysis to determine the cause for deficiency in operation shows that at twenty-five volts and 100 amperes the watts output, and therefore the heat, varies inversely with the arc volts, which condition is contrary to the requirements for arc stability and is evidently the cause for the deficient operation.

It has been found by test that if in the welding circuit shown in Figure 2, the battery voltage is increased to sixty volts and the resistor adjusted to obtain 100 amperes at twenty-five volts as illustrated in Figure 4, a welding arc can be maintained when using a ⅛-inch covered electrode. Examination of the watts output curve, B, in Figure 4 indicates that in this case the watts increase with an increase in voltage through the welding range, which, as previously stated, is necessary for arc stability.

It has also been demonstrated by test that if the circuit shown in Figure 2 is modified as indicated in Figure 5 by the addition of a reactor, X, even with a battery voltage of forty the circuit will have characteristics as indicated in Figure 6, and a stable welding arc will be obtained. In this case the volt-ampere characteristic and the watts output characteristic under rapidly changing conditions vary from the static characteristics, Curves A and B, in a manner indicated by the broken Curves A^1 and B^1, respectively. From Figure 6 it is noted that under rapidly changing conditions of arc resistance, due to the storage of energy in the reactor, the watts vary with the arc voltage, which, as previously stated, is a necessary condition for arc stability.

Behavior During Transient Short Circuits.

When welding with a covered electrode in the overhead and vertical positions of welding as well as when using light-coated electrodes in all positions, globules of molten metal frequently

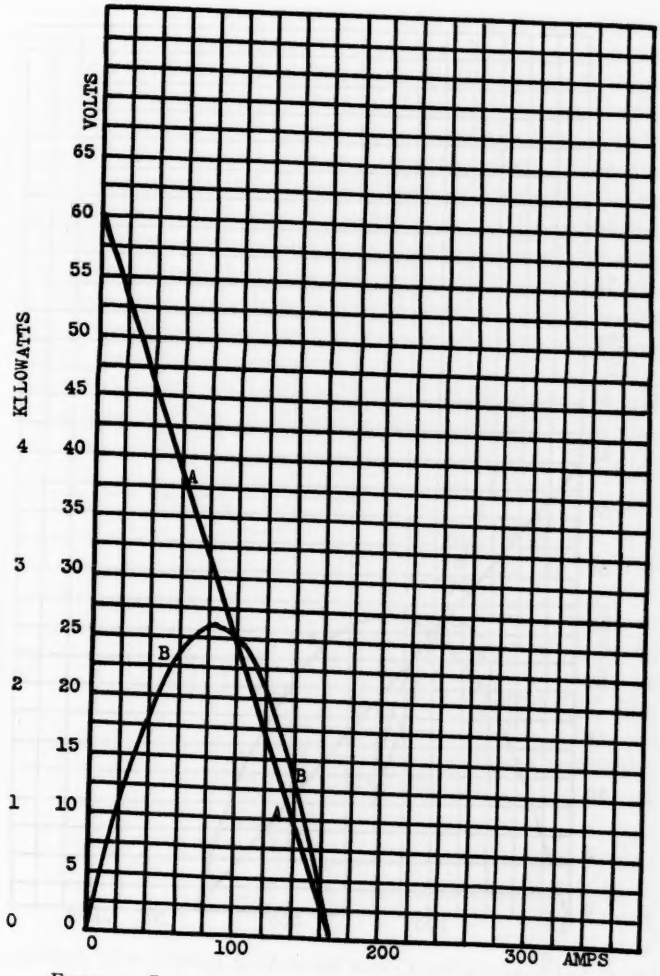


FIGURE 4—CHARACTERISTIC CURVES FOR 60-VOLT BATTERY WITH EXTERNAL RESISTOR.
CURVE A—VOLT-AMPERE CURVE.
CURVE B—WATTS OUTPUT CURVE.

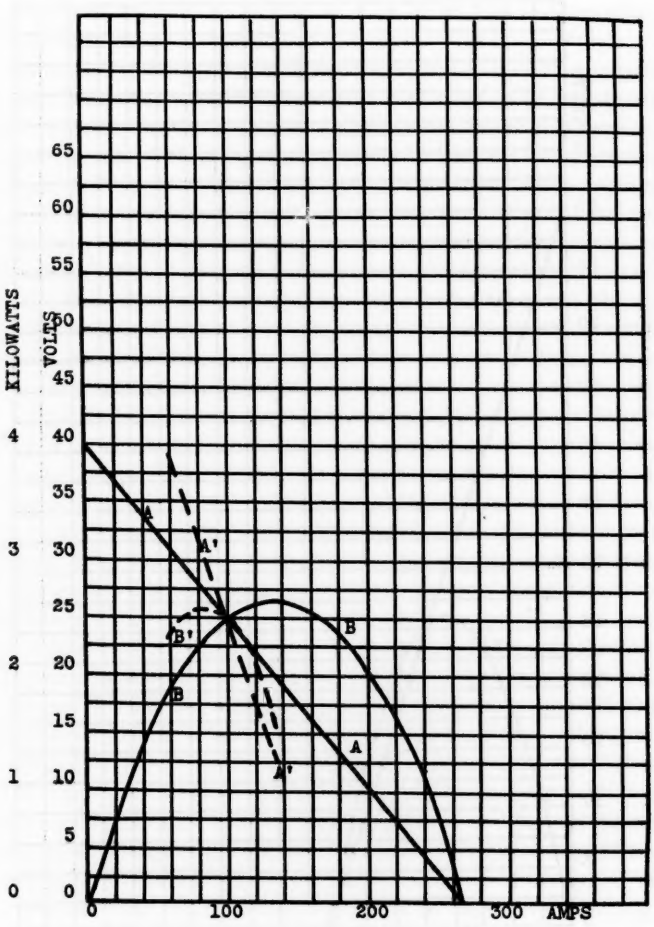


FIGURE 6—CHARACTERISTIC CURVES FOR 40-VOLT BATTERY WITH EXTERNAL RESISTOR AND REACTOR.

CURVE A—VOLT-AMPERE. CURVE A¹—VOLT-AMPERE (TRANSIENT).
CURVE B—WATTS OUTPUT. CURVE B¹—WATTS OUTPUT (TRANSIENT).

short circuit the arc, causing it to go out momentarily and to be re-established as the short circuit is opened by the complete passage of the drop of molten metal to the work. It has been found that it is important that the proper current and heat conditions be obtained during this short circuited period. Heat in this case is equal to I^2r where r is the resistance of the drop of molten metal. Since Figure 1 indicates that short circuited conditions generally do not continue for more than approximately .05 second the examination of various commercial welding circuits under conditions of short circuits for this period of time and their classification as to relative behavior for vertical and overhead welding using a covered electrode should indicate what are desirable behaviors under these transient short circuit conditions.

Figure 7 illustrates a constant potential multiple operator type welding generator, G; an adjusted external resistor, R; an elec-

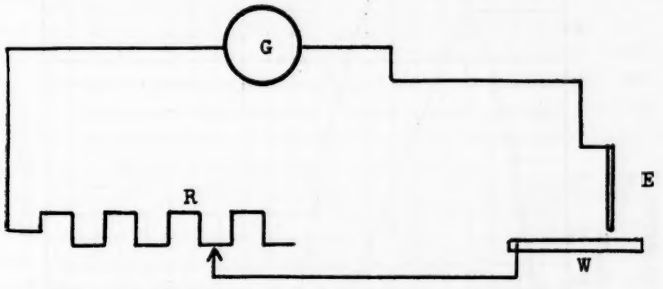


FIGURE 7.—ARC WELDING CIRCUIT CONSISTING OF CONSTANT POTENTIAL GENERATOR AND EXTERNAL RESISTOR.

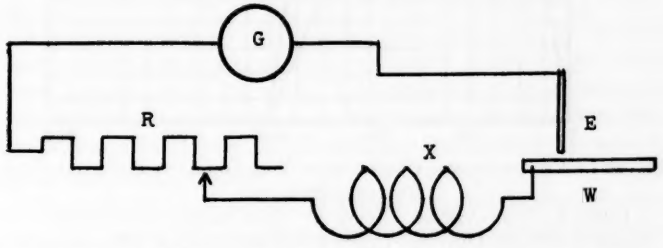


FIGURE 10.—ARC WELDING CIRCUIT CONSISTING OF CONSTANT POTENTIAL GENERATOR, EXTERNAL RESISTOR AND REACTOR.

trode, E, and the work, W. If it is assumed that the generator voltage is adjusted to seventy volts and the resistor is adjusted to give 175 amperes at thirty volts, normal welding conditions for 3/16-inch covered electrode, its characteristic curves are shown in Figure 8, in which curve A is the static volt-ampere character-

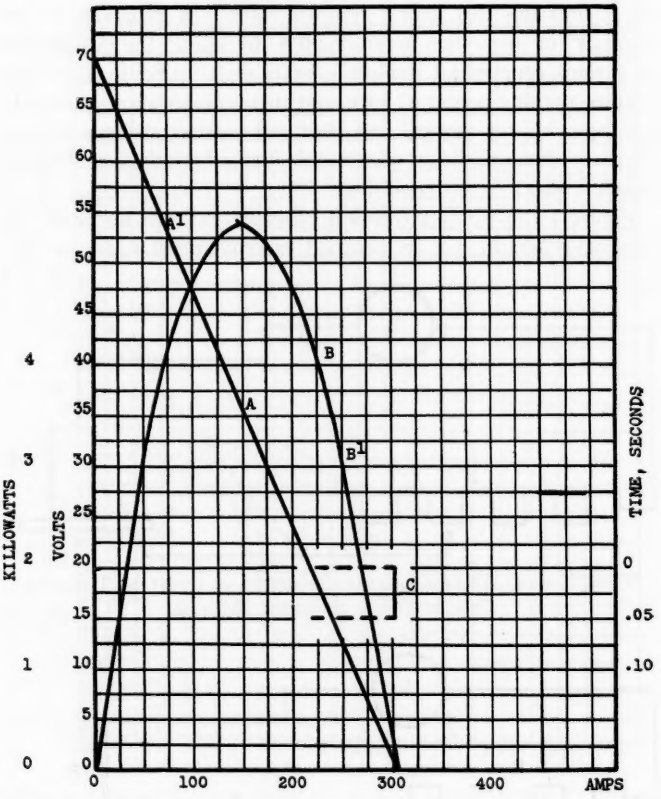


FIGURE 8.—CHARACTERISTIC CURVES FOR 70-VOLT CONSTANT POTENTIAL WITH EXTERNAL RESISTOR.

CURVE A—VOLT-AMPERE. CURVE A¹—VOLT-AMPERE (TRANSIENT). CURVE B—WATTS OUTPUT. CURVE B¹—WATTS OUTPUT (TRANSIENT). CURVE C—CURRENT-TIME, AFTER SHORT CIRCUIT.

istic and curve B is the static watts output characteristic. Since the capacity of the generator is relatively large and there is no appreciable reactance in the circuit it is assumed that the transient volt-ampere and the watts output characteristics coincide with the static characteristics under normal arc conditions. When a globule of molten metal short circuits the arc the current instantly increases to the final stable short circuit current, approximately 305 amperes, 175 per cent of normal welding current. The current remains at that value for the period of the short circuit and drops immediately to the current corresponding to the voltage of the arc having infinitesimal length. If it is assumed that the short circuit existed for .05 of a second, curve C of Figure 8 illustrates this transient current time characteristic during the short circuit.

If we assume that the generator voltage in Figure 7 is adjusted to 250 volts and the resistor adjusted to give 175 amperes at thirty volts as before, Figure 9 illustrates the characteristic curves for this condition. In this case, when a globule of molten metal short circuits the arc the current instantly increases to the final stable short circuit current, approximately 195 amperes, 110 per cent of the normal welding current. Again, if we assume that the short circuit lasted for .05 second curve C illustrates the current time curve during this transient short circuit.

It has been found under practical welding conditions, particularly when using covered electrodes in overhead and vertical positions, that the circuit condition illustrated by Figure 8 is more satisfactory than that illustrated by Figure 9. Arc stability under the conditions illustrated by Figure 8 are fairly satisfactory and arc stability as illustrated by Figure 9 is very satisfactory. The principal superiority of the welding circuit illustrated by Figure 8 over that in Figure 9 lies in the ability to obtain better penetration into sharp corners and more satisfactory transfer of the molten metal from the electrode to the work. Circumstantial evidence seems to indicate that this superiority is probably due to the higher current surge during the short circuited condition as illustrated by curve C in the two cases considered.

When the circuit illustrated by Figure 7 is modified by the addition of a reactor, X, as indicated in Figure 10, and the generator voltage adjusted to sixty volts and the resistor adjusted to give

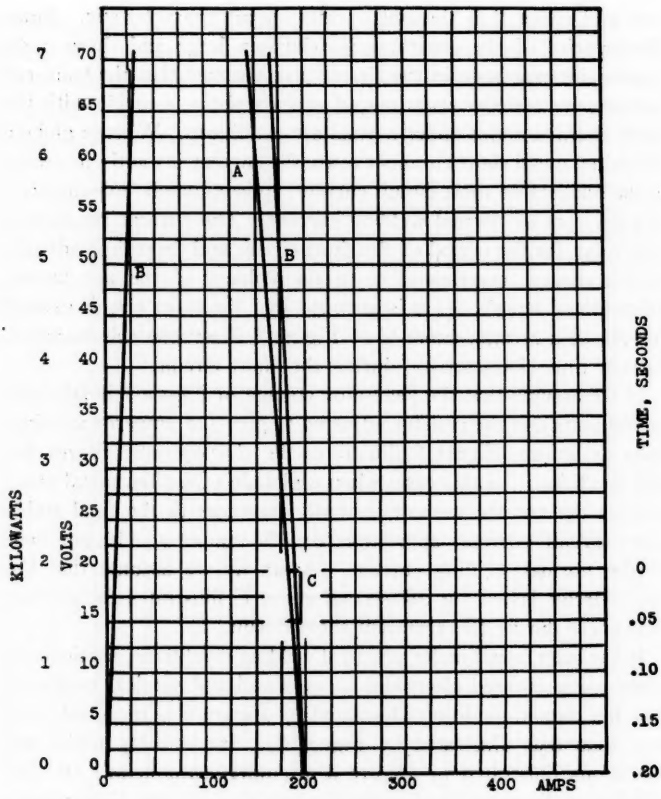


FIGURE 9.—CHARACTERISTIC CURVES FOR 250-VOLT CONSTANT POTENTIAL WITH EXTERNAL RESISTOR.
CURVE A—VOLT-AMPERE. CURVE B—WATTS OUTPUT.
CURVE C—CURRENT-TIME, AFTER SHORT CIRCUIT.

175 amperes at thirty volts as before, it will have the characteristics illustrated in Figure 11. In this case, when the drop of molten metal short circuits the arc the increase in current to the short circuited value will not be instantaneous due to the effect of the reactor, but if the short circuit lasts a sufficient length of time it will reach a value of 350 amperes, 200 per cent of the normal

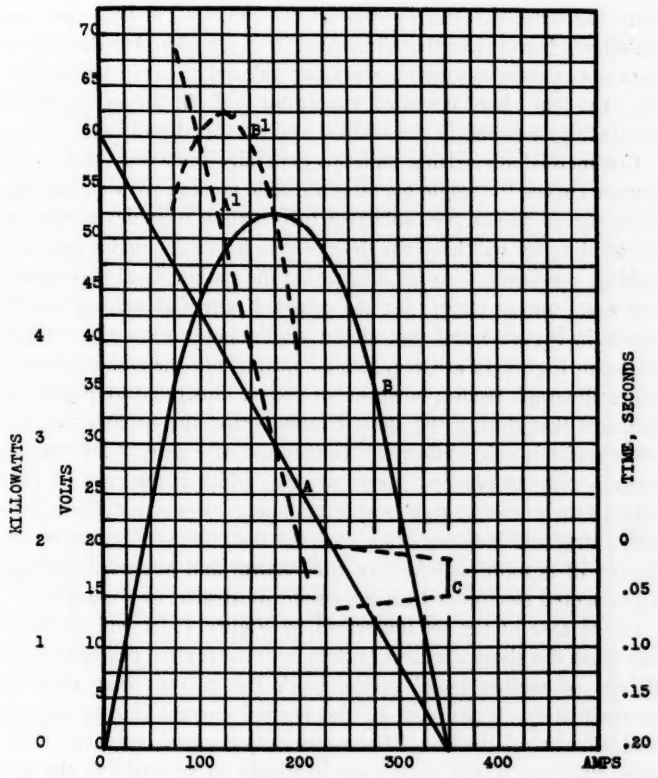


FIGURE 11—CHARACTERISTIC CURVES FOR 60-VOLT CONSTANT POTENTIAL WITH EXTERNAL RESISTOR AND REACTOR.
CURVE A—VOLT-AMPERE. CURVE A¹—VOLT-AMPERE (TRANSIENT).
CURVE B—WATTS OUTPUT. CURVE B¹—WATTS OUTPUT (TRANSIENT).
CURVE C—CURRENT-TIME, AFTER SHORT CIRCUIT.

welding current. When the short circuit is interrupted by the complete passage of the drop of molten metal to the work the current will not drop instantly to the value determined by the arc conditions, but the rate of decrease in current will be controlled by the effect of the reactor. If it is assumed that the short circuit existed for .05 second, curve C indicates the approximate current

time characteristic during the short circuit. In this case arc stability is better than that illustrated in Figure 8 and if the reactor does not contain too high a reactance value the current surge during transient short circuited conditions will be ample to insure satisfactory welding in the vertical and overhead positions.

Commercial advertising bulletins generally show only static volt-ampere curves for single operator variable voltage arc welding sets. Such curves do not give sufficient information to indicate whether the welding set will have the desired characteristics under practical welding conditions. As an illustration the static volt-ampere curves and watts output curves for the constant potential welding circuit shown in Figure 9 and that of the single operator variable voltage shown in Figure 12 are very similar throughout the welding range. An oscillograph record, however, of the set illustrated by Figure 12 indicates that during the short circuit period the behavior of the two circuits is quite different. In the case of Figure 9 the current surge is only 10 per cent above normal, while in the case of Figgure 12 the current surge is approximately 70 per cent above normal. Practical welding tests indicate that the set illustrated by Figure 12 is more satisfactory for vertical and overhead welding with covered electrodes than the circuit illustrated by Figure 9.

In the case of the set illustrated by Figure 12, it will be noted that when the short circuit is broken by the complete passage of the globule of molten metal to the work the current may drop to approximately 70 per cent of the normal current during the re-establishment of the arc. The watts output curve, however, indicates sufficient watts (heat) are available to re-establish the arc and provide ample arc stability characteristics.

Figure 13 shows the characteristics of another commercial type of single operator variable voltage arc welding set that has proved satisfactory under practical welding conditions. The transient volt-ampere curve and watts output curve are not shown. Curve C, however, shows the transient current time curve under the short circuit conditions. In this case it will be noted that the current surge is approximately 250 per cent of normal welding current. The current drops to approximately 70 per cent during the re-establishment of the arc but recovers to normal in sufficient time to provide satisfactory stability to the arc.

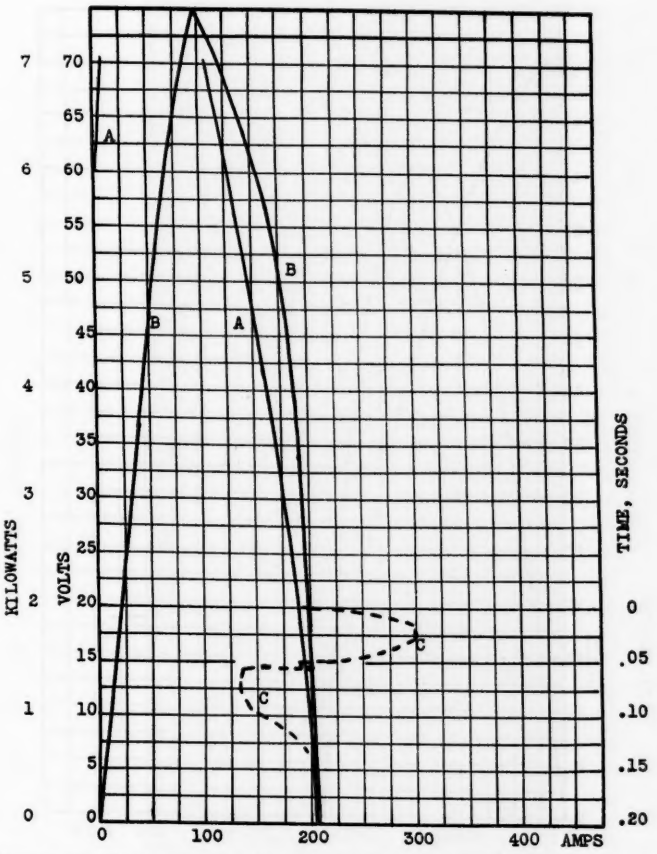


FIGURE 12—CHARACTERISTIC CURVES FOR COMMERCIAL WELDING SET WITH SERIES GENERATOR.
CURVE A—VOLT-AMPERE. CURVE B—WATTS OUTPUT.
CURVE C—CURRENT-TIME, AFTER SHORT CIRCUIT.

The watts output curve in Figures 12 and 13 indicate conditions satisfactory for arc stability up to voltages considerably above normal and these sets contain reactance which further improves their arc stability characteristics.

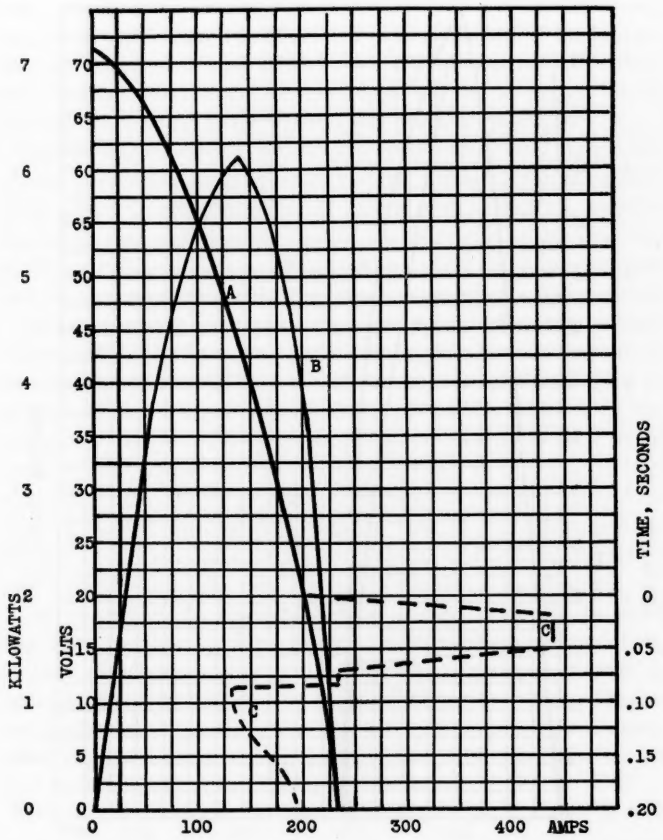


FIGURE 13.—CHARACTERISTIC CURVES FOR COMMERCIAL WELDING SET WITH SHUNT GENERATOR.
CURVE A—VOLT-AMPERE. CURVE B—WATTS OUTPUT.
CURVE C—CURRENT-TIME, AFTER SHORT CIRCUIT.

Figure 14 is an oscillograph record of welding current for voltage furnished by a set of the type illustrated by Figure 13 without external reactance. In this case the current surge during the

RATING - 200 AMPS.
SETTING - 200 AMPS. full field
TEST - Welding without reactance
700
600
500
400
300
200
50
25
0

FIGURE 14.

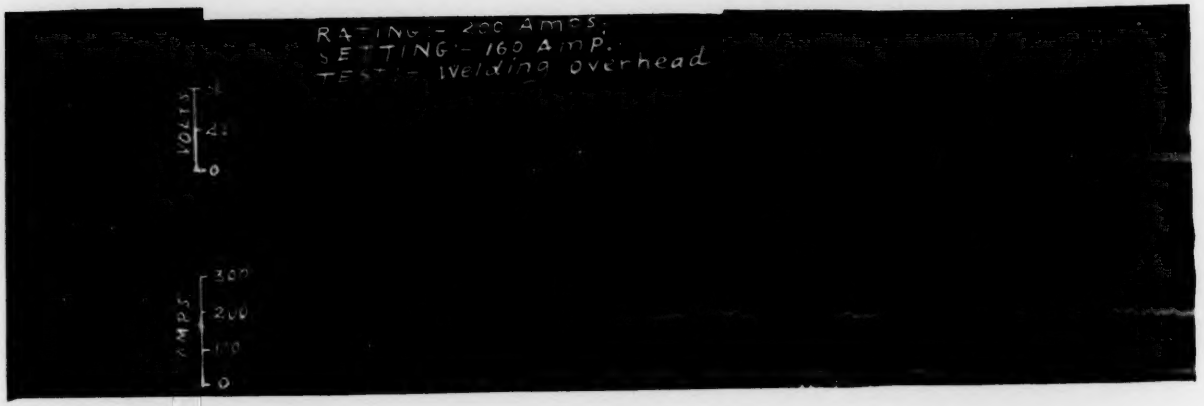

RATING - 200 AMPS.
SETTING - 160 AMP.
TEST - Welding Overhead
VOLTS
40
0
AMPS
300
200
100
0

FIGURE 15.

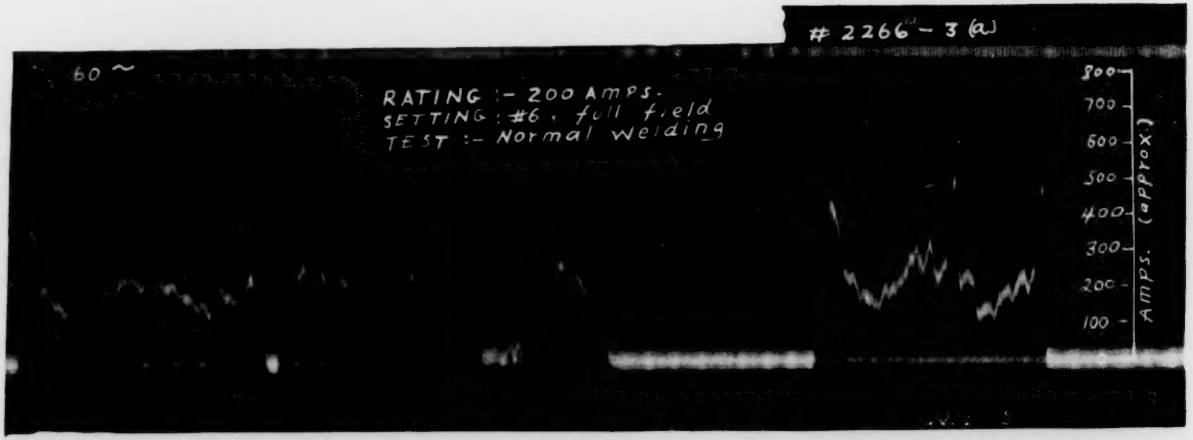

#2266-3(a)
60 ~
RATING :- 200 AMPS.
SETTING : #6 , full field
TEST :- Normal Welding
800
700
600
500
400
300
200
100
AMPS. (approx.)

FIGURE 16.

short circuited period is approximately 250 per cent of normal. Figure 1 shows the volt-ampere characteristics of the same set with normal reactance of the circuit, in which case the current surge during the short circuit is approximately 175 per cent normal.

Figure 15 is the oscillograph record of welding circuit conditions of relatively large amount of the reactance in which case the current surge was approximately 110 per cent of normal. It was generally observed that under this condition arc welding in vertical and overhead work were inferior to that obtained by sets having the characteristics illustrated in Figure 1.

Figure 16 is the oscillograph record of welding current provided by a set having poor voltage recovery under normal load conditions.

Conclusions.

Investigations along the lines discussed in this paper indicate the following:

A. In order to meet the requirements of arc stability, if the welding circuit does not contain an appreciable reactance, the voltage corresponding to maximum watts output must be appreciably higher than the arc voltage or sufficient reactance must be added to the circuit to obtain the arc stability. The addition of reactance is equivalent to increasing the maximum watts output during transient conditions.

B. Welding circuits or welding sets having constant current characteristics under the transient conditions do not provide the most desirable results. Therefore, arc welding sets or circuits should not contain unnecessarily high reactance.

C. The current surge when a globule of molten metal short circuits the arc should be an appreciable value perhaps somewhere between 50 per cent and 150 per cent above normal. This matter should be further investigated to determine more definite limits as to the desirable value.

D. Voltage recovery under normal load conditions as specified in the Navy Department Specifications 17W1 is a more satisfactory standard than the voltage recovery under no load conditions specified in the standards of the American Institute of Electrical Engineering.

E. Standards for electric arc welding sets and circuits should include the following:

(1) Limits for the time of recovery under normal load.

(2) Limits for the slope of static volt-ampere curve at arc voltages or minimum limits to the voltage at which maximum watts output occurs.

(3) Maximum and minimum limits for the current surge under practical welding conditions when a globule of molten metal short circuits the arc for a specified period such as .05 second.

NOTES.

INDEX TO NOTES.

CONTROLLABLE PITCH PROPELLER.
—Teknisk Tidskrift, Stockholm, Sweden, July 16, 1938.

THE VENTILATION OF SHIPS.
—The Engineer, London, England, October 20, 1939.

THE S. S. EXPORTER.
—The Nautical Gazette, New York, N. Y., September 23, 1939.

C-1 VESSELS OF THE U. S. MARITIME COMMISSION.
—Pacific Marine Review, San Francisco, Calif., September, 1939.

THE VOITH-SCHNEIDER SYSTEM OF PROPULSION.
—Engineering, London, England, September 15, 1939.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

A French Rotating Boiler.
—Combustion, New York, N. Y., November, 1939.

The Airflex Clutch for Diesels.
—Motorship and Diesel Boating, New York, N. Y., September, 1939.

Duramold—A Structural Material.
—The Aeroplane, London, England, July 26, 1939.

Tanker With New Form of Stern.
—Shipbuilding and Shipping Record, London, England, August 3, 1939.

CONTROLLABLE PITCH PROPELLER.

This translation is from a lecture by Dr. H. F. Nordstrom before the Swedish Technological Society, Division for Naval Architecture. The lecture was delivered at the regular Spring meeting, May 6, 1938, then published in the July 16, 1938, issue of "Teknisk Tidskrift." Dr. Nordstrom is Professor at the Royal Technical University, Stockholm, in charge of the Department for Naval Architecture. He is the author of numerous pamphlets and books published in several languages. The translation and rewriting is by J. H. Strandell, Associate Engineer, Diesel Engine Design Section, Bureau of Engineering and Bureau of Construction and Repair, Navy Department, Washington, D. C.

The idea of using propellers whose pitch can be changed from the interior of the ship to suit the driving condition is very old, though, so far, its application has been limited to fishing craft. For these the controllable pitch is quite important. Usually the movement of the propeller blades is purely mechanical and applied to very small powers. Lately there has been a great deal of work done in improving the mechanism, particularly through the use of hydraulic actuation, thereby extending the idea to large powers.

Because of the renewed interest in variable pitch propellers, it is desirable to investigate the advantages such a propeller may have for ships in general. In the following are given practical examples of such application:

Given: *The propeller diameter and the main characteristics of the engine.*

Shaft horsepower ..... $N_o = 450$ HP.
Speed of rotation ..... $n_o = 132$ RPM.
Torque ..... $M_o = 2440$ mkg.
(mkg. = kilogram meter)
Speed (in still water and no wind) ..... $v_{so} = 11.0$ knots
Wake factor ..... $W = 0.10$
Speed relative to ship's wake ..... $v_{eo} = (1\text{-}W)\ v_{so} = 5.08$ meters/sec.

Hence, following values for propeller:

Diameter ..... $D = 2.86$ meters
Pitch ..... $H = 2.86$ meters
Number of blades 3
Au/Ad (Ratio Projected Area to Disc Area) 0.45

For this propeller, which has been calculated for idling, it is now possible to compute the thrust for speeds other than v_{eo}. This requires an assumption concerning the engine characteristics. We proceed from the simple assumption that for speeds of rotation less than n_o the torque M_o is constant, that is, the power available is proportional to n (see Figure 1). At $n = n_o$ it is assumed that a governor controlls the engine in such a manner that the power drops to zero.

The dotted lines in Figure 1 indicate the variation of thrust T, propeller efficiency η, relative horsepower N/N_o and relative revolution n/n_o, with the speed relative to ship's wake v_e. It is evident that for $n < n_o$ the curves for n/n_o and N/N_o are identical. The corresponding speed of advance of the ship is also given under the assumption that the wake factor has the constant value $W = 0.10$.

The above applies only to the propeller when the pitch is constant. If we now use the same calculation method * for the case of constant diameter and variable pitch and also assume both speed n_0 and torque M_0 constant, that is the power is constant, the results obtained may not be exact, but they are descriptive enough to illustrate the advantage of a controllable pitch

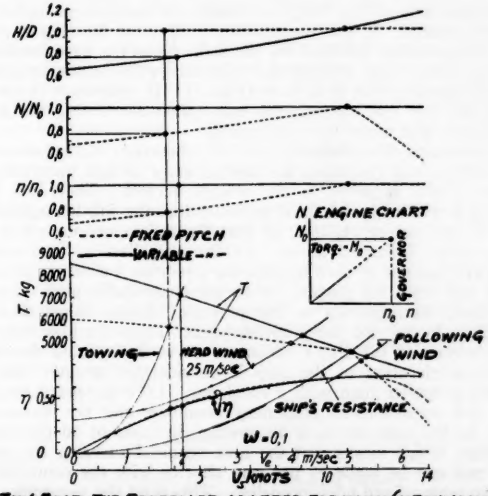


FIG 1. TOW-BOAT. THE PROPELLER ADAPTED FOR IDLING (NO TOWING LOAD) DIFFERENCE BETWEEN FIXED AND VARIABLE BLADES D = DIAMETER OF THE PROPELLER H = PITCH, N = SHAFT HORSE POWER, n = THE REVOLUTION OF THE PROPELLER, T = THRUST FORCE, η = THE EFFICIENCY OF THE PROPELLER w = WAKE FACTOR, V_s = THE SPEED OF THE SHIP, V_e = SPEED RELATIVE TO SHIPS WAKE = $(1-w)V_s$

propeller at towing. (It will be shown in the following that an adjustable propeller blade can have constant pitch only in one position. The influence of the relatively large hub as a consequence of the mechanism necessary for variable pitch will also be mentioned later on.) The results of these calculations are represented by the full drawn curves in Figure 1. As indicated by

* Space does not permit a description of the method used in these calculations. Several methods are available. In the present case the calculations are based on model tests obtained at the K. T. H.'s shipbuilding testing station with propellers of D = 0.150 meters. The results are expressed through the propeller characteristics, that is to say $\frac{I}{\delta D^4 n^2}$, $\frac{M}{\delta D^5 n^2}$ and η as function of the expression $\frac{v_e}{D.n}$. A fixed pitch-ratio requires a propeller with one set of characteristics that corresponds to the pitch-ratio, while for variable pitch-ratio a number of different combinations of propeller characteristics has to be used. " Schaffran's " curves derived from $\frac{I}{D^2 H^2 n^2}$, $\frac{M}{D^2 H^3 n^2}$ and η as functions of the " real " slip $\left(1 - \frac{v_e}{H.n}\right)$ can be used for determining the propeller dimensions.

the curves in Figure 1, the variable pitch propeller gives a much larger thrust T than the fixed one. This does not with variable pitch depend on the efficiency of the propeller, but on the fact that full horsepower is taken out at all speeds; for a fixed pitch propeller the horsepower N/N_o decreases at reduced speed.

The curves referred to above depend only on the propeller and the engine and are independent of the ship in which the machine-propeller-diameter combination is placed. If now the resistance curve for the ship in question at dead calm (the propeller adjusted for the wake factor) is superimposed on the thrust curves, it must pass through the point where the broken and full drawn curves for T intersect, that is at $v_o = 11$ knots. If this result is not obtained it is due to the fact that the original assumption concerning the relation of shaft horsepower and speed was not correct.

In this connection the following may be observed: Calculations of propellers as well as hull resistance are always more or less uncertain, and the manufacture of the propeller is not always perfect. Therefore, it is not uncommon on a trial trip with fixed propeller that the full horsepower, N_o, at revolutions n_o can not be realized, or that the resistance curve will not pass through the point indicated above. If the propeller is "too small" the full horsepower can not be used because the governor (which is here assumed to be used) will limit the power. With the controllable pitch propeller, on the other hand, discrepancies in the propeller design calculations can be compensated for by varying the propeller pitch. From the difference between the thrust curves and the ship's resistance curve it is noted that the force available for acceleration of the ship is considerably greater with a controllable pitch propeller than with a fixed one. (We disregard the fact that our curves are applicable to stationary condition and not to acceleration condition.) In this case we have an average increase of 30 per cent in the effective thrust, which means that the time required to bring the ship up to speed from rest can be made 23 per cent shorter with the controllable pitch propeller than with a fixed pitch propeller. This is on the assumption that the pitch is varied gradually in accordance with the full drawn H/D-curve in Figure 1. We also assume that the time required to accelerate the engine may be neglected in both cases.

By means of the thrust curves in the two cases above mentioned, we are now in a position to study the conditions when the ship's resistance differs from that for which the propeller was calculated, due to a different loading condition of the ship, different wind, light vs. heavy towing, running in ice, etc.

For example, in Figure 1 a curve is plotted which represents the total resistance when the ship is running against the wind. The wind velocity is assumed to be 25 meters per second. The additional wind resistance which is added to the ship's own resistance at dead calm has been calculated by means of the formula

$$R = .06 \, A \left(25 + \frac{v_e}{1 + w}\right)^2 \text{ kg.}$$

Where R is the additional thrust in kilograms, $A = 40$ M^2, the projected area above the waterline in square meters and v_e = speed of ship in meters per second.

This formula also includes a factor for the resistance due to rough sea. From Figure 1 it appears that when the pitch can be suited to the prevailing conditions an increased speed at maximum horsepower of about 0.45 knots will be reached as compared with the use of a fixed propeller. The reason

is evidently that in the former case the engine power can be fully used, while in the latter case the propeller speed is reduced to $n/n_o = 0.91$ and the corresponding horsepower $N/N_o = 0.91$. For a following wind and assuming that the governor is set for the speed n_o, the resultant resistance curve will be below the resistance curve of a dead calm. In the case of a fixed pitch propeller the governor throttles the power before the full value is reached, while for a controllable pitch propeller the full effect may be reached. To utilize the maximum horsepower the pitch must be adjusted to the wind; for wind astern the pitch should be greater, and for a head wind less than the normal pitch. When towing, the propeller thrust must overcome the resistance of the towed objects (barges, timber rafts, etc.) as well as the ship's own resistance. In Figure 1 an assumed combined resistance curve is plotted, representing towing. Apparently the towing speed, in this assumed case, can be kept considerably higher (about 0.5 knots) with controllable pitch than with the fixed pitch propeller. As stated before, this follows from the fact that in the former case the full engine power is used, while in the latter case the horsepower as developed by the engine is considerably less than N_o. The same reasoning can be applied concerning conditions when the ship has to contend with ice.

In this connection it should be pointed out that when the engine is provided with a variable speed transmission it is possible with a fixed propeller to utilize the full horsepower of the engine. Assuming a fixed pitch propeller and constant power for all speeds a thrust curve is obtained which is slightly below the full drawn T-curve in Figure 1. The difference is due to the losses in the transmission.

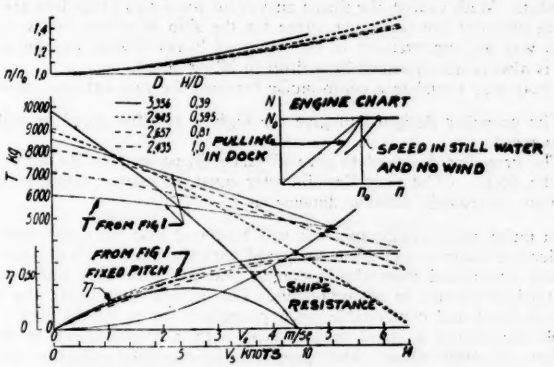


FIG 2. PROPELLER FOR THE TOW-BOAT IN FIG. 1 DESIGNED TO USE FULL ENGINE POWER AT "STALL PULL" (FIXED BLADES)

In the preceding example the normal propeller has been designed principally to suit the idling condition, still water, no towing load or wind. The propeller can be, and often is applied to towboats so that the propeller is designed for a certain towing condition; for example, the condition of a dock trial, that is $v_o = 0$ or unity slip ratio. Figure 2 illustrates this case

of four different propellers having different pitch ratios, absorbing full horsepower N_o at n_o RPM.

The largest thrust is obtained from the propeller with the smallest pitch ratio, but at the same time the diameter becomes too large for the vessel in question. Furthermore, it appears that greater thrust can be obtained with fixed pitch propellers and a diameter designed on the basis of the best possible propeller at dock trial, that is $v_o = 0$, than could be obtained before with controllable pitch propellers.

Figure 2 also gives T, η and n for different values of v_o and the assumption that the engine power is constant N_o for all speeds. (See engine chart in Figure 2.) This means that the speed may exceed n_o and we must assume this to be possible. All these fixed blade propellers give a lower speed in still water and no wind when compared with the propeller specially designed for that condition. The speed of the ship in still water and no wind would be even poorer if the engine was provided with a governor set for the speed n_o.

Any one of the propellers in Figure 2 may now be assumed to be provided with variable blades. Under this condition the pitch may be adjusted so that the speed n is constant $= n_o$ and the power $= N_o$ for all values of v_o. In this case the propellers of interest are those having a greater thrust when pulling from dock than was obtained with a controllable pitch propeller designed for speed in still water and no wind. This is comparable in the present example to propellers with pitch ratio H/D less than 0.65, that is, propellers with the diameters 2.945 and 3.356 meters. As pointed out before, however, the propeller having the greater diameter is too large for the vessel in question. With $v_o = 0$, the thrust curves for these two propellers are higher, but will intersect the resistance curve for the ship at speeds below 11 knots. In this way an improvement in the range of heavy towing can be achieved, but it is always accompanied by a drop in idling speed.

We may also visualize a compromise between the two extreme cases:

1. The propeller designed to give the highest possible speed in still water and no wind.
2. The propeller designed to give as large thrust as possible when pulling from the dock. (The propeller diameter must, of course, conform to local conditions as regards limiting dimensions.)

Even under these compromises it will be found that the controllable pitch propeller has many merits when compared with the fixed pitch propeller.

It was anticipated from the beginning that a controllable pitch propeller for a towboat should be advantageous. Let us now investigate the relative merits of fixed and controllable pitch propellers for a freight ship. As an example we choose a small freight boat with a displacement in the load condition of 1600 tons. The propeller is designed on the following assumptions:

Torque ..... $M_o = 2400$ mkg.
Speed of revolution ..... $n_o = 120$ RPM.
Shaft horsepower ..... $N_o = 409$ HP.
Speed of ship ..... $v_{so} = 9.0$ knots
(In load condition and no wind)
Wake factor ..... $w = 0.256$
Speed relative to ship's wake.... $v_{eo} = 9 \times 0.5144\ (1 - 0.265) = 3.447$ meters/sec.

This gives $D = H = 2.80$ meters

The propellers are designed on the basis of calculations similar to those in the former example with fixed pitch $H = 2.80$ meters and with controllable pitch varied in such a way that N always $= N_o$ and $n = n_o$. Propeller diameter in both cases is to be 2.80 meters. As may be noted from the engine chart in Figure 3 for n less than n_o three cases are assumed as follows:

1. Constant torque $= M_o$.
2. Constant horsepower $= N_o$.
3. Constant speed of rotation $= n_o$ (Governor).

In the chart is plotted the ship's resistance curve in loaded condition and with no wind. As noted above, the propeller is designed to suit this case. The resistance curve for the ship with no load is also plotted. In both cases the curves have been adjusted for the propeller wake factor. Finally, the resulting resistance curve at loaded condition and head wind of 20 meters per second is plotted.

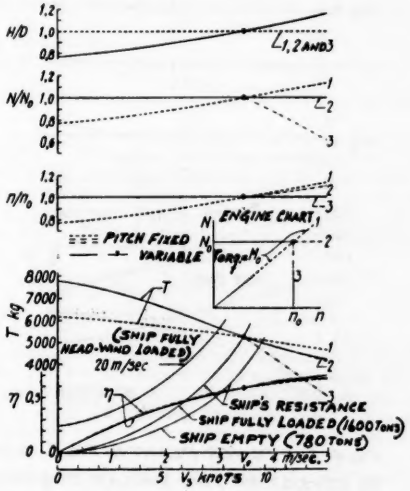


FIG 3 THE DIFFERENCE BETWEEN FIXED AND VARIABLE PITCH PROPELLER FOR A SMALL FREIGHT BOAT. $w = 0.256$ (assumed)

It is evident, from the point of view now under consideration, that the advantages of the controllable pitch propeller are not as great as those in the case of the towboat. It is still true, however, that the time for starting the ship may be reduced with variable pitch; full horsepower N_o can be used in all situations; and slight deviations in the propeller design from the optimum efficiency can be adjusted.

Figure 3 in its main feature can be said to be typical of a ship of any kind. Therefore, we can use Figure 3 for studying the conditions of a ship with several propellers. We assume that a ship is provided with three engines of the same horsepower, working on individual propellers. For the sake of simplification, we first assume that all three propellers are alike and that when running the propeller thrusts are equally divided among the three. Each propeller works against a load of ⅓ of the ship's resistance (adjusted for the propellers' wake factors). If we now let Figure 3 represent the center propeller, its resistance curve will evidently represent one-third (⅓)

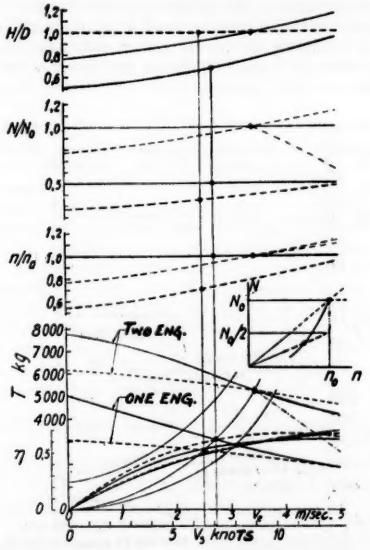


FIG. 4 THE POWER-PLANT IN FIG. 3 IS ASSUMED TO CONSIST OF TWO SIMILAR ENGINES WORKING ON A COMMON PROPELLER SHAFT. THE CURVES SHOW THE DIFFERENCE BETWEEN FIXED AND VARIABLE PITCH PROPELLER WHEN ONLY ONE ENGINE IS RUNNING.

of the ship's resistance. Assume next that only the center engine is working and that the two other propellers are idling and have negligible resistance. In this case it is evident that the working propeller has to overcome the total resistance of the ship. The intersection between the curve just described and our previously obtained thrust curves will show the difference between the case when the center propeller is provided with controllable blades and

when it is provided with fixed blades. In the first case full horsepower of the working engine can be used, while in the second the speed of rotation will decrease, followed by a reduction in horsepower and the consequent reduction in the speed of the ship, until the limiting torque of the engine is obtained.

In the present example we now assume that we have two equal engines connected together in the same way to a common propeller shaft. We assume further that the operating condition of the ship is such that it is sometimes desirable to run both engines and at other times only one. The propellers are assumed to be calculated on a basis of the ship fully loaded and both engines at full horsepower giving maximum speed to the ship. We thus arrive at the same propeller as before, that is, $D = H = 2.80$ meters.

The question is what will occur when only one engine is working, in one case with a fixed pitch propeller and in the other case with a controllable pitch propeller. Figure 4 gives the answer to this question. As noticed at full loading condition, the speed of rotation of the working engine will go down to $0.7n_o$ and hence, the horsepower will be reduced to $0.7 \frac{N_o}{2}$* if the propeller has fixed blades.

With the variable pitch on the other hand, if the pitch ratio is changed to about 0.69, the full engine horsepower $\frac{N_o}{2}$ can be used. The difference in the resultant speed of the ship will be about 0.6 knots in favor of the controllable pitch propeller. A similar condition occurs when the ship is unloaded. Another very interesting comparison can be made when the ship is pulling away from the dock, using one engine and controllable pitch propeller, it exerts a pull of 5000 kilograms, but when two engines are used with fixed propellers, the pull is only 6200 kilograms, that is, only 24 per cent larger.

Problem of an Actual Ship.

Given the Propeller Diameter:

We will next investigate the advantages a controllable pitch propeller offers in the case when the ship has to operate under reduced speed for such long periods that the fuel consumption at those speeds becomes of importance. An example of this is what is called the "cruising speed" of a war vessel. In order to have a general view of the problem, let us again take a concrete example.

We assume that for a certain twin screw ship (torpedo boat) we know the required thrust-horsepower ($T.v_e$) per propeller at different speeds; that is, we know the ship's resistance adjusted for the propeller's wake factor. We start from the following values:

$v_s = 20$ knots ($T.v_e$) ..... = 980 HP.
$v_s = 25$ knots ($T.v_e$) ..... = 2520 HP.
$v_s = 30$ knots ($T.v_e$) ..... = 4810 HP.
$v_s = 35$ knots ($T.v_e$) ..... = 7310 HP.
$v_s = 40$ knots ($T.v_e$) ..... = 10270 HP.

On the basis of the required thrust at 40 knots, which is assumed to be maximum ship's speed, we start from an engine speed $N_o = 520$ RPM. and

* True theoretical value of horsepower at the reduced speed by Frouds Law of Comparison would be $\left(\frac{\sqrt{2}}{2}\right)^3 N_o = .352\, N_o$. —(Translator's note.)

assuming a wake factor of $w = 0.06$ we arrive at the following best propeller dimensions (without consideration to cavitation):

$$D = 2.46 \text{ meters}, \quad H = 2.73 \text{ meters}; \text{ that is, } H/D = 1.11.$$

For the propeller diameter as worked out above we can for each speed, for instance 30 knots, calculate the required shaft horsepower at different RPM., at the same time obtaining the corresponding pitch. Similar calculations have been made for 35, 25 and 20 knots, using in all cases a constant value of $w = 0.06$. The results of these calculations are given in Figure 5. Every point on these curves for constant speed corresponds to a certain pitch; that is, to a certain pitch-ratio. By connecting points corresponding to the same pitch-ratio, curves for constant pitch-ratio have been obtained. It is evident

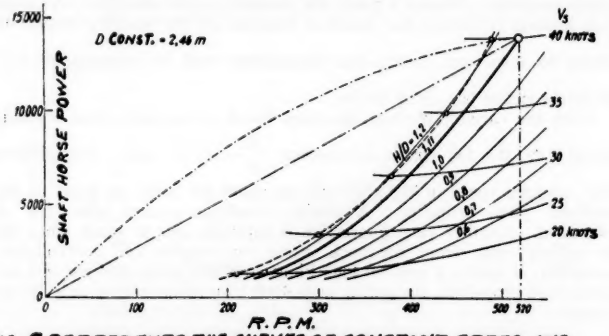


FIG. 5 REPRESENTS THE CURVES OF CONSTANT SPEED AND CONSTANT PITCH-RATIO RESPECTIVELY AT A GIVEN PROPELLER-DIAMETER AND A GIVEN RESISTANCE CURVE FOR THE SHIP. THE SMALL CIRCLES INDICATE THE MINIMUM POINTS ON THE CURVES FOR CONSTANT SPEED. THE CURVES FOR A LARGER PITCH-RATIO THAN 1.2 ARE NOT SHOWN. THE FAMILY OF CURVES ARE REPRESENTATIVE OF A CASE IN GENERAL. THE DASH AND DOTTED CURVES INDICATE ASSUMED BOUNDARY CURVES FOR STEAM TURBINE AND DIESEL ENGINE OR RECIPROCATING STEAM ENGINE RESPECTIVELY.

that the curve for pitch-ratio 1.11 (derived for the propeller designed above) will intersect the 40-knot curve at 520 RPM. Since $D = 2.46$ meters and the fixed pitch $= 2.73$ meters, we must remain on the curve for 1.11 pitch-ratio. The curve can be obtained for the propellers in question at test runs with progressive speeds, provided there is an arrangement to measure the shaft horsepower. The rest of the curves for constant pitch-ratio give a clear idea about the situation when the propellers are provided with variable pitch.

The family of curves obtained applies only to propellers of $D = 2.46$ meters combined with a ship with the above assumed resistance curve. (For instance, if the resistance curve changes due to currents or wind the family of curves

will be distorted.) It should also be pointed out that this family of curves is characteristic for all such combinations of a propeller of given diameter and a ship with a given resistance curve.

In connection with Figure 5 the following comments may be made:

As before in another connection, we recognize that propeller design calculations not obtaining the optimum propeller efficiency (when the curve for $H/D = 1.11$ does not intersect the top point of the curve characteristic of the engine) can be corrected through a small resetting of the blades. If we assume that the speed of rotation n_0 does not fit in because of propeller or shaft vibration and that it must be reduced somewhat, Figure 5 shows that the decrease in the speed of the ship with a controllable pitch propeller (through increase of the pitch) may be kept smaller than with a fixed propeller.

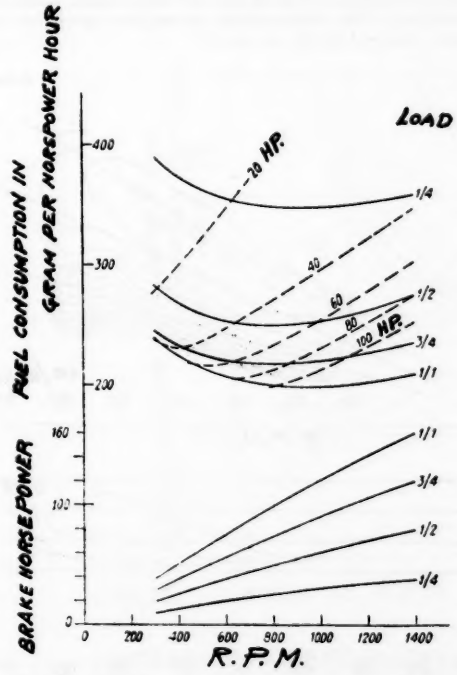


FIG 6 FUEL CONSUMPTION PER HORSEPOWER HOUR OF A "BOLINDER" DIESEL ENGINE FOR VARIOUS MAIN EFFECTIVE PRESSURES

From a study of Figure 5 it will be further recognized that the overload capacity of the engine can be used more effectively with controllable pitch propeller than with a fixed one. In Figure 5 it will be noticed that a curve has been drawn through the minimum points of the curves for constant speed. This curve is located very close to the curve representing $H/D = 1.11$. This is typical for a general case. Furthermore, it is typical that the curves for constant speed are very flat in the neighborhood of the respective minimum points. From this it may be established that in general there is hardly any reason to use a controllable pitch propeller in order to obtain a good propeller efficiency at reduced speeds.

If we require, on the other hand, that the smallest fuel consumption per horsepower hour should be obtained at reduced speeds, the conditions are quite different, and a controllable pitch propeller seems to offer considerable advantage. In order to study this question closer, we must know the fuel consumption per horsepower hour for the whole speed range of the engine which will be used. The characteristic curves for the engine should overlap the previously obtained family of curves.

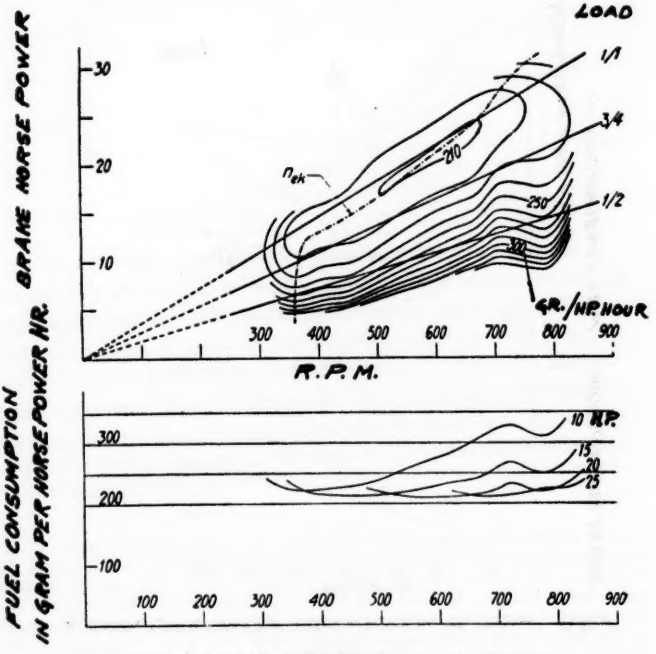


FIG 7. FUEL CONSUMPTION PER HORSEPOWER HOUR OF AN "ATLAS" DIESEL ENGINE

Figure 6 shows the variation of fuel consumption per horsepower hour for a Bolindar Diesel engine type W7L4. Similar information is represented in greater detail in Figure 7, which applies to a 25-HP. Atlas Diesel engine. In the chart is plotted a curve marked n_{ek}, which is obtained by connecting the tangent points of horizontal tangents to the "profile curves." From this curve we may obtain the speed of rotation which corresponds to the minimum fuel consumption per horsepower hour.

Both examples shown above refer to small Diesel engines, but Diesel experts have informed me that they regard the examples as typical of Diesel engines in general, including all sizes. If this is the case, we may draw the conclusion that the minimum fuel consumption occurs at a lower speed with controllable pitch propeller than with fixed pitch propellers. If the propeller is provided with variable pitch, the pitch ought to be increased (above the normal pitch) until the point is reached (RPM.) where the smallest fuel consumption per hour is obtained. This point will be located somewhere between the curve for fixed pitch (normal pitch) and the curve n_{ek} (Figure 7).

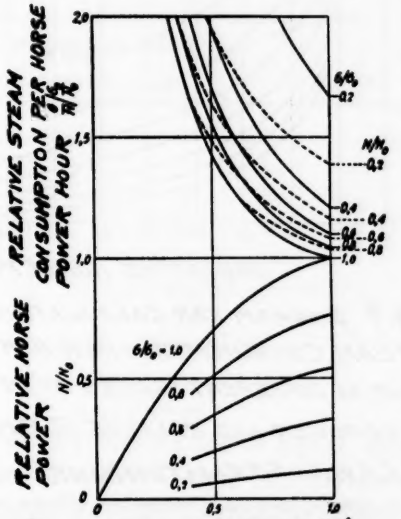


FIG 8. RELATIVE R.P.M. n/n_0

STEAM CONSUMPTION PER HORSE-POWER HOUR FOR A "DE LAVAL" STEAMTURBINE AT CONSTANT STEAM CONSUMPTION PER HOUR RESPECTIVELY CONSTANT HORSEPOWER

It would have been of great value to have at my disposal a similar diagram for reciprocating steam engines. So far, I have been unable to collect sufficient data to draw such a diagram.

The conditions of a De Laval steam turbine deviate from those above applying to Diesel engines. Figure 8 applies to a steam turbine of this type and the curves are made up (in a form not indicating any dimensions) on the basis of data furnished by Mr. V. Nordström, president of "De Laval Steam Turbine Corp." The curves in Figure 8 show the steam consumption per horsepower hour, and thus the fuel consumption, at constant horsepower,

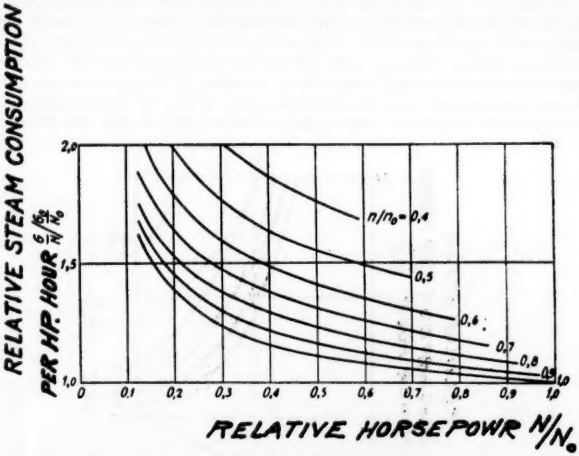


FIG. 9 DIAGRAM FOR CALCULATING RELATIVE STEAM CONSUMPTION PER HORSEPOWER HOUR AT DIFFERENT VALUES OF RELATIVE HORSEPOWER AND RELATIVE R.P.M. FOR A "DE LAVAL" STEAMTURBINE.

which has an opposite tendency in comparison with the corresponding curves for Diesel engines, since the steam consumption decreases with increasing RPM. The family of curves shown in Figure 9 has been plotted by the use of Figure 8. With the help of these the relative steam consumption per horsepower hour can be determined for each combination of horsepower and speed within the range of the turbine.

The family of curves in Figure 9 has been applied to a special case (a small naval vessel) with the following conditions:

The ship provided with two De Laval steam turbines.

Full shaft-horsepower on each propeller.....$N_o = 1520$ HP.
Corresponding RPM. at full shaft-horsepower.....$n_o = 365$ RPM.
The speed at full horsepower.....$V_{so} = 19$ knots
Wake factor .....$W = 0.084$

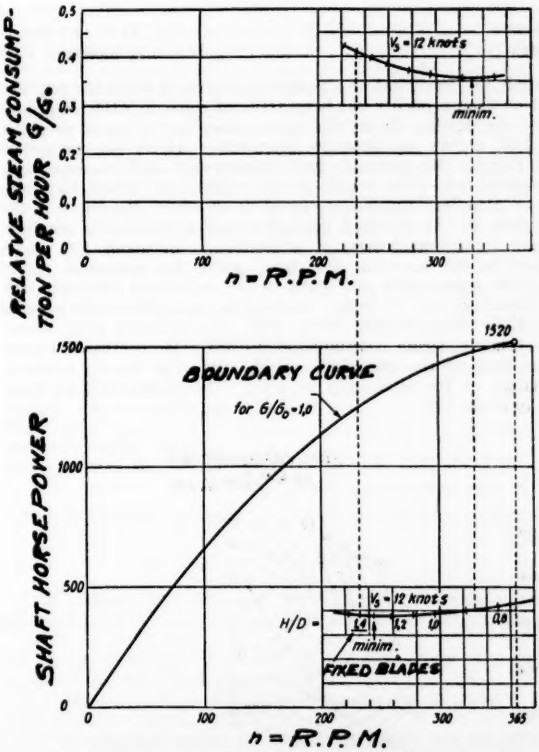


FIG. 10 THE CURVES REPRESENT A SMALL WARVESSEL PROVIDED WITH TWO "DE LAVAL" STEAMTURBINES (WITHOUT "CRUISING TURBINES") MAXIMUM SPEED 19 KNOTS. THE CONDITION OF EACH PROPELLER SHAFT IS SHOWN AT REDUCED SPEED OF 12 KNOTS, AND THE COMPARISON OF STEAM CONSUMTION PER HOUR BETWEEN THE FIXED PITCH PROPELLERS AND THE VARIABLE PITCH PROPELLES.

On the basis of these conditions the following main dimensions have been calculated:

Propeller diameter ..... D = 1.65 meters
The normal pitch ..... H = 2.31 meters = 1.4D

In order to study the conditions at a reduced speed of 12 knots the required propeller thrust on each propeller has been assumed equal to 3240 kilograms, independently of the RPM. With this assumption, and using a propeller diameter D = 1.65 meters at different pitch-ratios H/D, the propeller-efficiency (and thereby the required shaft horsepower) and corresponding RPM. can be calculated. The result of this calculation, which has been done by means of Schaffran's propeller curves, is shown by the curve in the lower part of Figure 10. As indicated, the best propeller-efficiency is acquired, that is, minimum shaft horsepower, at a pitch-ratio of about 1.3, which comes very close to the 1.4 value calculated above for maximum speed. Using Figure 9, the upper curve in Figure 10 can be plotted, indicating the relative steam consumption at 12 knots. As may be noted, the relative steam consumption at H/D = 1.4 is about 0.411, while the minimum point corresponds to the relative steam consumption = 0.355. A decreased steam consumption per hour of the magnitude of 13.5 per cent can be achieved through the change of the pitch-ratio to 0.87. The RPM. will increase from about 230 to about 330.

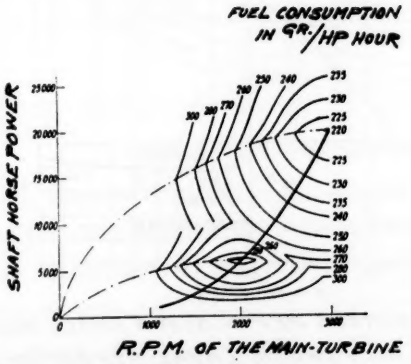


FIG 11. FUEL CONSUMPTION PER HORSE POWER HOUR FOR A "STAL" STEAMTURBINE PROVIDED W. A "CRUISING SPEED TURBINE"

I have shown this example because a conclusive calculation has been possible. However, this example has little actual value because the turbine power plant in question uses a special turbine for the purpose of reducing steam consumption at cruising speed. This special turbine (cruising turbine) is designed for the RPM. which suits a fixed pitch propeller, and in this case a change in pitch would not give improvement in steam consumption (see also

Figure 11). According to data I received, we should in the present example be able to figure with a relative steam consumption of about 0.30. The example does not propose any "cruising turbine" and can be assumed to have importance in such cases where it is desired to simplify and cheapen the cost of the power plant through excluding the "cruising turbine." We will find that with controllable pitch propellers the reversing turbine may also be excluded, but in place of it a governor is needed.

In this connection there is shown in Figure 11 the fuel consumption per horsepower hour of a "Stal-turbine" provided with a "cruising turbine" to be used for cruising speed. The curve chart is made up on the same principle as Figure 7; that is, the fuel consumption is indicated through "profile" curves for constant fuel consumption. If we disregard the speed range in which the cruising turbine is used, we find that at constant horsepower the fuel consumption per horsepower hour decreases with increasing RPM. (compare with Figure 8). On the chart, which is calculated and plotted by the Swedish Turbine Mfg. Corp. Ljungström, Finspong, Sweden, is based on the following data:

Steam pressure ..... 40 atmospheres
(1 atmosphere = 14.7 pounds per inch^2)
Steam temperature ..... 475 degrees C.
Cooling water temperature ..... 15 degrees C.
Boiler efficiency ..... 87 per cent
Auxiliary engine losses ..... 5 per cent
The heat value of the fuel oil ..... 10,500 kcal/kg.
(kcal/kg. = kilogram calories per kilogram)

NOTE 1—Figure 11 covers the case of two turbines of 10,000 HP. each.

MANEUVERING.

It is obvious that propellers provided with controllable pitch offer many advantages during maneuvering. The most important are the following:

1. It has been pointed out that the starting of the ship can be made more quickly than with fixed pitch propeller.
2. With controllable pitch propeller, reduction in speed of the ship can be made without manual regulation of the engine. The most natural thing to do is to decrease the pitch. However, the engine has to be provided with a governor. (Decrease in speed can also be accomplished through increase of the pitch. At least that is the case with machinery where the limiting horsepower of the propelling machinery has already been reached and the engine must slow down as increased torque is applied.)
3. By continuous turning of the blades a location will be reached where the thrust is zero in spite of the fact that the propeller is in continuous rotation. The position of the blades depends on the speed.
4. By further rotation of the propeller blade angle a negative thrust is obtained with resulting retardation of the vessel's speed and reversing of the ship's direction.

The propeller shaft continues to rotate at constant speed in the same direction throughout this maneuvering, which may be made very rapidly; no reversing means are needed.

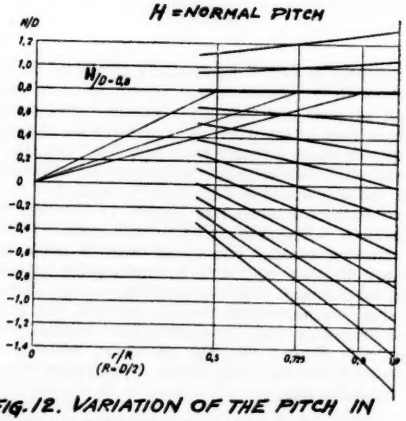


FIG. 12. VARIATION OF THE PITCH IN RADIAL DIRECTION WHEN TURNING THE BLADES OF A PROPELLER WITH NORMAL PITCH-RATIO =0.8. THE PITCH IS DETERMEND FROM PITCH ANGLE AT THE TURNING AXIS.

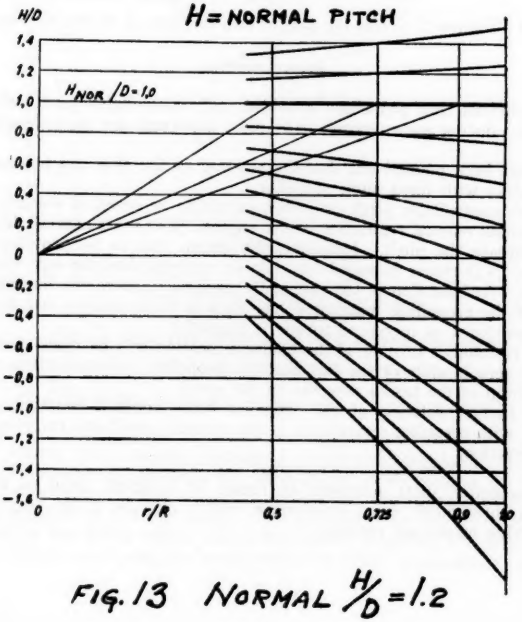


FIG. 13 NORMAL $H/D = 1.2$

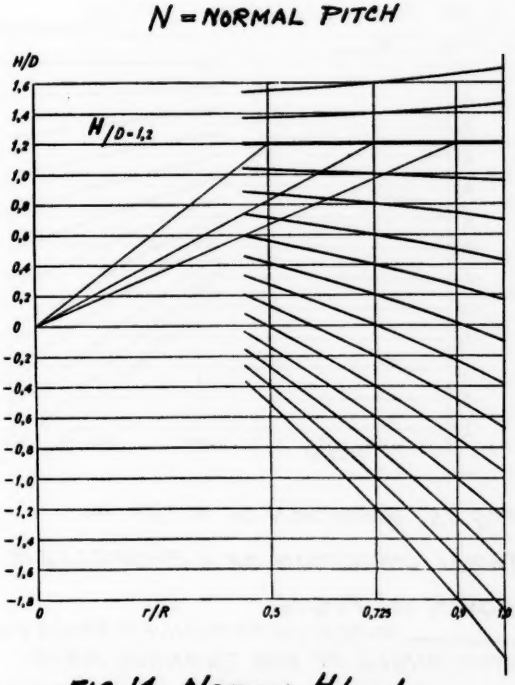


FIG. 14 NORMAL $H/D = 1.2$

THE PITCH CHANGES IN A RADIAL DIRECTION WHEN TURNING THE BLADES.

If the propeller blades in a normal position on the normal pressure side are parts of a helical surface, this will no longer be true when the blades are shifted. For the sake of simplicity, we assume that the axis of rotation, which we assume to be perpendicular to the propeller axis, coincides with a certain mean generatrix of the blade. (We recognize that the assumption does not impose any limitation on the design. Figures 12-15 will thus remain unchanged if the turning axis and the main generatrix do not coincide, but are parallel.)

Under this assumption Figure 12 shows how the pitch-ratio varies in radial direction for different turning angles of the blades with a propeller of normal pitch-ratio 0.8. The point of origin represents both the turning axis and the main generatrix. The unit for the scale H/D is naturally $\frac{1}{\pi} \times$ unit for the scale of r/R. The three rays shown in the figure extending from the point of origin and corresponding to the relative radii 0.5, 0.725 and 0.9 will keep

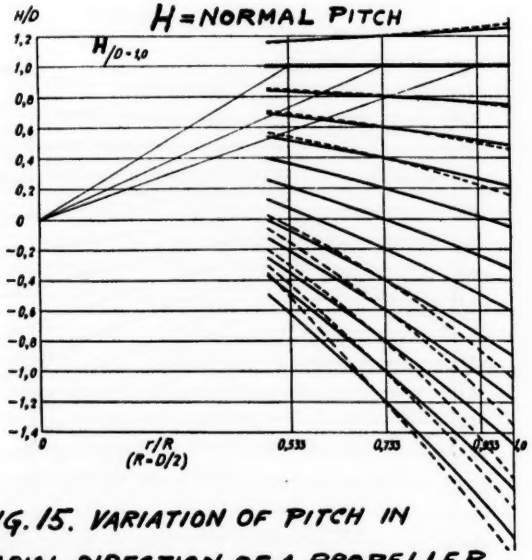


FIG. 15. VARIATION OF PITCH IN RADIAL DIRECTION OF A PROPELLER SHOWN IN FIG. 16

——— PITCH DETERMINED FROM THE PITCH-ANGLE AT THE TURNING AXIS

– – – – – – PITCH DETERMINED THROUGH MEASUREMENT.

their relative location while turning. This bundle of rays has turned in such a way that the middle ray intersects the ordinate $r/R = 0.725$ in a series of even values of H/D; and the underlying idea is that the pitch $r/R = 0.725$ may be regarded as an average pitch for the whole blade. The rest of the rays' intersection with the ordinates and radii, respectively, determine the pitches at those radii.

In Figures 13 and 14 similar diagrams are made up for H normal/D = 1.0 and 1.2, respectively.

In Figures 12-14 the pitch and the pitch-ratio at different radii are determined by the pitch-angle at the axis. It is also possible to define the pitch at different radii in the ordinary way by measuring the difference in height in an axial direction between extreme points of the blade. The pitch is then calculated by the formula $H = \frac{360}{a} h$, (h = difference in height, a = opening angle, seen in the direction of the propeller shaft, between the measured

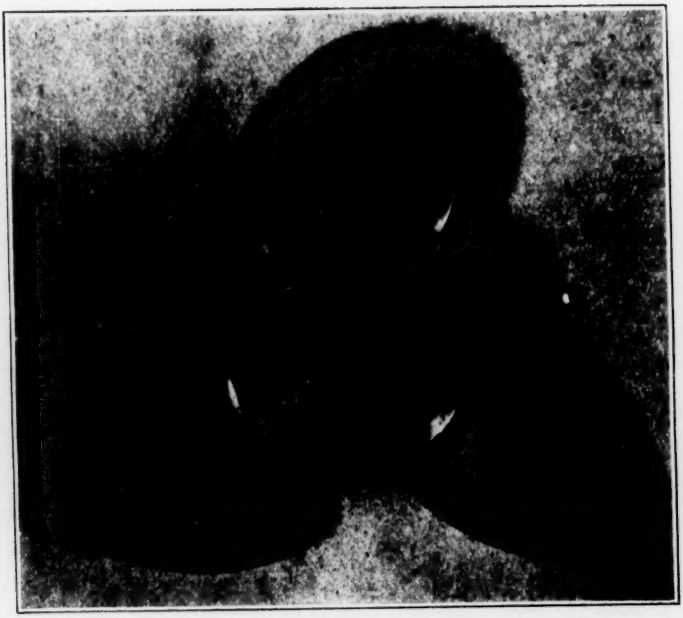


FIGURE 16.

points). The result of such a measurement, on the propeller shown in Figure 16, is given in Figure 15. In Figure 15 the full lines are obtained in a similar manner as those in Figures 12-14, while the broken lines are obtained through direct measurement of the radii in the figure; these deviate somewhat from those used in Figures 12-14. During the measurements, every blade has been adjusted in such a way that the pitch, according to the latter principle, at the point $r/R = 0.733$ has received an even value (1,2, 0.6, etc.) and the basis of the above adjustment the measurements at the radii $r/R = 0.333$ and 0.933 have been made.

As apparent, from Figures 12-15, the pitch in radial direction will not be constant while turned from the normal position. In the region around the normal position (that is, at relatively small movements, such as occur at full speed ahead) the changes are negligible and these variations have been shown to be of very little importance to the propeller efficiency. On the other hand, it is quite common (for example, the so-called wake-current propeller) to have the pitch of the propeller vary from the true helix, the pitch of the blade increasing slightly as the radius is increased. If we wish to keep the deviation from the true helical surface as small as possible, within the usual operating range, we can do this by slightly decreasing the normal pitch.

At greater turning of the propeller blades, for example such as occurs when reversing the direction of the ship, a considerable variation in pitch in radial direction is apparent. A decrease in propeller efficiency under the above condition is inevitable, but, as the propeller is only operated under this condition for short periods, the loss in efficiency is unimportant. No final experiment of this matter has as yet been made. From the preliminary tests at the K.T.H.'s shipbuilding testing station, it appears that the propeller efficiency using a controllable pitch propeller while the ship is going astern is fully acceptable. In connection with the above it can also be pointed out that with a controllable pitch propeller the full power of the propelling engines can be used at full speed astern, which is not the usual case when a fixed propeller is used.

Relation of the Hub to the Propeller Diameter.

It is obvious that the hub diameter of a variable pitch propeller should be relatively larger than for a fixed pitch propeller. With fixed blades the

$$\frac{\text{hub diameter}}{\text{propeller diameter}}$$

is ordinarily of the magnitude 0.2, while at variable blades we must calculate with figures of 0.25 to 0.35.

The propeller action is such that the blade elements towards the center do less of the work of the propeller than those which are located further out. From this point of view it is probable that a reasonable increase of the hub diameter does not need to decrease the propeller efficiency to any extent, if at the same time the stream lining of the hub is well made. In this matter no final test has been concluded, but the preliminary tests, which have been made at the K.T.H.'s Shipbuilding Test Station, apparently indicate that a hub diameter of up to 0.35 D can be used without any appreciable decrease of the propeller efficiency.

Reference of Literature.

William McEntee: Model tests with adjustable blade propellers. Trans. Soc. Nav. Arch. Mar. Eng. 1927.

Melitta Schiller: Auswertung experimenteller Untersuchungen uber Luft- und Wasserschrauben mit verdrehbaren Flugelblattern. Hydromechanische Probleme des Schiffsantriebs, Hamburg, 1932.

F. Gutsche: Verstellpropeller. A.V. d. I. 1934, page 1073.

THE VENTILATION OF SHIPS.

This paper is abridged from an article by R. McDonald in the "Journal of the Institution of Heating and Ventilating Engineers," August, 1939. It shows the practice in the ventilation of merchant ships that results from control by the British Board of Trade. The paper in its present form was published in the October 20, 1939, issue of "The Engineer," London, England.

The rules that govern the installation of a heating and ventilating system on board ship must of necessity be very different from those we are accustomed to ashore because of the difference structurally. The restriction and congestion, too, on board ship is a problem which makes it difficult to reconcile ventilation principles ashore with principles afloat.

The Board of Trade authorities are responsible for the comfort conditions of third-class passengers and crew, but strangely enough where first-class passengers, second class or tourist class are concerned, there are no rules to be enforced as regards heating and ventilation, but it is an unwritten principle that by virtue of their class, these passengers must have nothing inferior to what is laid down by the Board of Trade for third class, steerage, emigrants, or officers, engineers and crew.

It will be observed, therefore, that the basis of requirements for ventilation is that which is stipulated by Board of Trade.

A third-class passenger is allowed a minimum of 15 square feet deck area and 830 cubic feet of air per hour air supply by mechanical means, with an additional 33 per cent air supply if the accommodation is located in the bowels of the vessel or adjacent to machinery spaces. In actual practice a figure of 1000 cubic feet of air per hour per person is allowed as the minimum for third class and crew, which, relative to the cube of the space occupied by the individual, ensures at least 8 changes of air per hour. As these are minimum requirements and, therefore, represent ⅔ duty by speed reduction of maximum fan output it follows that in summer conditions when the fans are running at top speed, there will be 12 air changes per hour available or 1500 cubic feet of air per hour per person. Where a vessel is equipped for world tours and must encounter tropical conditions a maximum of 15 air changes is often provided, particularly in accommodation below decks, which is equivalent to approximately 2000 cubic feet of air per hour per person.

The same air change is given to first class and second and tourist class passenger accommodation, but because a person in this class is allowed more cube or deck area relatively than third class or crew occupy, the quantity of air available for the higher class corresponds to 3000 to 4000 cubic feet per hour per person.

It will be at once obvious that there is a considerable difference between these conditions and those which apply to the requirements for buildings on land, but it has been found from experience that this is unavoidable (*a*) because of the congested nature of things aboardship, and (*b*) because of the necessity for rapid air movement in tropical conditions approaching 100 degrees F., where the relative humidity is high and where heat gains are considerable, and where the dissipation of this heat is demanded as quickly

as possible to give tolerable comfort to room occupants. It is an argument for air cooling by refrigeration that by its adoption the quantity of air used normally could be greatly reduced and, therefore, save a great deal in the initial cost of ventilating plant; but on the other hand, the cost of refrigerating machinery is a big item and the running cost considerable.

But whatever may be said about air conditioning, whether it will come to stay or not, one thing is certain, and that is that mechanical ventilation is now considered imperative. Shipbuilders and shipowners are gradually realizing the importance of it for the success of their vessels. For, after all, the success of any ship or building depends not upon the beauty of the external appearance, but upon the internal comfort, and heating and ventilation of the right kind contribute very largely to the latter.

General Practice.

Recent vessels built to operate in all-sea conditions are equipped with separate heating and ventilating systems, and thus approach the more perfect ideal which has been generally realized by heating and ventilating engineers for many years where first-class buildings on land are concerned.

In the most up-to-date vessels the steam-heating system is generally of the vacuum low-pressure type, the pressure of steam not exceeding 5 pounds per square inch and the temperature rise being such that the system will be capable of maintaining a temperature of 65 degrees or 70 degrees F., as may be desired in passenger rooms, corridors and public rooms. In North Atlantic waters the temperature rise of the air is taken as from zero or minus 10 degrees F. and in the Pacific as from 32 degrees F.

Insulation.

While on the subject of heating it may be advisable to introduce at this stage the all-important question of insulation as a sound investment, and as a preventative against excessive heat losses and the resultant heavy running and maintenance costs. Shipowners and builders are reluctant to realize the value of insulating the exposed walls and ceilings of living rooms and public rooms of vessels against excessive heat losses in winter conditions and heat gains in summer and tropical conditions.

It is particularly important to stress the point where winter conditions are concerned, for it is here that the greatest saving would occur. In summer or tropical climates the heat gains are mainly from the passengers themselves and from electric lights and other such apparatus, but it would be undoubtedly well worth while where large public rooms are concerned and where the exposed surfaces are large so that the quantity of air introduced could be at a lower rate of air change per hour than has been found necessary so far. But for a vessel which sails regularly in the bitter cold of Atlantic conditions, there can be no doubt whatever that insulating the exposed surfaces (on the inside, of course) with 2-inch-thick non-inflammable cork slabs would be well worth while.

The exposed walls and ceilings of passenger accommodation are formed of an outer skin of steel plating, a 6 to 10-inch dead-air space to the face of the frames or beams as the case may be, and a wood, plaster or composite panelling of ½ or ¾-inch thickness, the combination of which constitutes the equivalent of an exposed area having a transmission coefficient of approximately 0.5 Btu. per square foot per degree difference per hour. In arriving at this factor allowance has been made for northerly or easterly exposure and wind resistance of high velocity. This high coefficient empha-

sizes that as it approaches twice the coefficient for the 14-inch-thick brick wall of a respectable sized building on land, the need for insulation to be applied is very apparent and not to be lightly disregarded.*

The effect of applying 2-inch-thick cork to the exposed surfaces of passenger and public-room accommodation would be to reduce the value of the coefficient of transmission to about 0.15 Btu. per square foot, which reduces the factor 3½ times. To carry this still further, it will be at once obvious to the engineer versed in the problem of heating and ventilating that a considerable saving in fuel and running cost must accrue with the adoption of cork or other suitable material as an insulating medium.

VENTILATION.

To pass from the question of heating to the question of ventilation, which is the larger of the two propositions where ships are concerned, it is necessary to sectionalize the systems, which, although entirely independent, are nevertheless co-relative.

(a) Crew Accommodation.

As already explained, crews' quarters come under direct supervision of the Board of Trade, who have laid down comprehensive rules and regulations for the guidance and observance of the ventilating engineer.

In up-to-date vessels, mechanical extract obtains from the alleyways instead of natural ventilation. It is also usual practice where a mechanical system of fresh-air supply is installed to crews' rooms for two or more fans to be so arranged that it will be possible to link up one system with another so that in the event of one fan failing or being out of commission, an interconnecting duct with an isolating-damper arrangement can be opened up to permit a supply of air under all conditions. The same conditions apply in the case of third-class passengers or emigrants, as these also come within Board of Trade ruling.

(b) Passengers' Accommodation.

As a general rule fresh-air supply only is provided direct to passengers' rooms by mechanical means on the basis already outlined, *i. e.*, at 12 to 15 air changes per hour under maximum operating conditions, reducible to 8 to 10 air changes per hour in winter conditions. The maximum amount of air available per person works out at between 3000 and 4000 cubic feet per hour.

Occasionally direct extract from rooms is provided, but this normally applies to special cabins or suites which are isolated from the ordinary alleyways and passages and therefore from the public lavatories. As a general rule the extract from passenger accommodation is of an indirect nature; that is, via louvers or gratings in the doors or partitions into the alleyways and removed from thence either direct to atmosphere, but more often by the extract ventilating system obtaining in the lavatories or sanitary services.

Third-class passenger rooms must have separate extract having no connection with lavatory ventilation, and this is often done by large natural ventilators in the rooms or corridors or by mechanical means.

The principle of air distribution in passengers' rooms is carried out either by means of adjustable ball-type high-speed fittings, large regulating gratings, or by air diffusers, which are of considerably less area than gratings, but admit the same quantity of air.

* As a rule the exposed walls of crews' quarters have no wood or composite lining, and the steel plating is either painted or thinly cork dusted, so that the coefficient of transmission may be as high as 2 Btu./per sq. ft./per degree difference per hour for conditions of 5 to 10 degrees F. of frost, and 2.5 for North Atlantic or Baltic conditions.

For many years the ball-type or punkah-louver fitting was extremely popular as a departure from the ordinary wall-type grating or grille and undoubtedly the fitting has decided merit in that it is small, unobtrusive, and universal in operation, the principle being its capability of admitting large quantities of air at high speed in any desired direction to obtain rapid cooling effect.

Unfortunately for this type of fitting, rapid cooling also depends on the temperature and *humidity* of the air being introduced from outside, and a jet of air at high speed which has no cooling properties can warm up the anatomy just as rapidly as it can cool it down if the temperature drops suddenly, as it sometimes does in the tropics, with a resultant heavy deposit of moisture and the attendant alarming results.

Indeed, it is now being realized that the high-speed outlet is not desirable in passenger accommodation for the simple reason that "throw" is not essential where the space is limited and height is already very low, and where it is difficult to evade a high-speed stream of air except by diverting it on to a partition wall or ceiling.

Which brings us to the conclusion that *diffusion* of air without draught is the most desirable condition, *not concentration*, and that a room can be more satisfactorily cooled by general distribution, not isolated intensity of air flow.

To produce this ideal method of air distribution there are now on the market fittings of British design which allied to a duct system can definitely admit large volumes of air to a room at approximately 1000 to 1200 feet per minute velocity, without draught or discomfort to the room occupants and which produce equable distribution of the air in all directions simultaneously. The design of these fittings is such that they are eminently suitable for incorporating with the electric-light fittings on the walls or ceilings, projecting no more than a few inches, and also readily harmonize by circular, square or rectangular shape, with any scheme of decoration as may be desired. Combined with these fittings there is a device by which, if desired, directional delivery can be obtained by very simple adjustment.

As already implied, these fittings can admit similar quantities of air to the high-speed fittings, but with different effect, and the same quantity of air as effectively and noiselessly as would be admitted by a grating four times as large.

To obtain and maintain constant desirable temperatures the time must surely come when the value of the thermostatic valve will be appreciated and regarded as indispensable for controlling the air-heater batteries or heating systems, so that whatever tendency there may be for other influences to affect the desired temperature, the source of admitted heat will be controlled decisively, not only to ensure comfort but to effect saving.

(c) Sanitary Services.

In the first, second or tourist classes the lavatory extract system, although entirely separate in fact from the stateroom ventilation, is indirectly responsible for removing the vitiated air from the staterooms via the louvered doors and partitions of the staterooms into the alleyways and from thence through the gratings or louvered arrangement in the entrance doors to the lavatories, the main alleyways being the intermediate connecting link between the one system and the other. It is imperative, therefore, that ample provision be made both in stateroom doors or partitions adjoining the corridors and likewise in the lavatory doors or partitions, so that there will be no restriction or resistance to the flow of air from living rooms to lavatory. This is very important.

The system is quite successful when correctly designed and safeguards the accommodation from any unpleasantness due to the vicinity of sanitary arrangements. It is sometimes considered advisable to introduce just a small amount of fresh air direct to the lavatories to supplement and freshen the larger volume obtained via alleyways.

The success of this system also depends upon the amount of extract obtaining in the lavatories and which, because of the principle described must be at a high rate of air change.

In actual practice, therefore, 20 to 30 air changes per hour extract is the standard set, and to arrive at this basis it is assumed that of the volume of fresh air supplied direct to cabins it is only necessary to remove about 50 per cent by the lavatory extract system, the other 50 per cent providing pressure to offset infiltration through portholes, alleyways, staircases, etc. On the principle of so much lavatory and bathroom space in direct proportion to living rooms, this arrangement works out very well. The inner walls or partitions of lavatories, w.c.'s and bathrooms, are left open at top and bottom so that adequate air movement will take place within the confines of these services.

(d) Public Rooms.

Generally, public rooms aboard ship are given more air than staterooms, measured on the basis of air change, because it will be appreciated that less area is allocated per person for seating arrangements than pertains to the passengers' living rooms. It also follows that if more persons occupy less room there will be a greater amount of casual heat to be dissipated, and this fact combined with the amount of heat gains from electric lights and large surfaces of structure walls make it essential for larger air changes to obtain than applies to passenger rooms.

For this reason also fresh air and extract ventilation is essential, entirely apart and distinct from any other system, and the balanced system of equal fresh air and extract is the usual arrangement with perhaps, on regulation, a slight excess of fresh air to counteract infiltration and maintain slight pressure outwards.

The rate of air change may be anything from 15 to 20 times per hour, depending, of course, on the nature of the public room, whether lounge, reading room, drawing room, music room; the location in the vessel; the number of people to be seated; the structural peculiarities, whether exposed or sheltered, and so on.

Smoke rooms, card rooms and bars are given special treatment in the respect that if the quantity of fresh air required should be determined as 15 air changes per hour, it is advisable to provide extract at the rate of 20 air changes per hour, to combat the tendency for smoke and fumes to escape to surrounding or adjacent public rooms or accommodation.

Where public rooms occur below decks, that is to say in the lower parts of the vessel, it is generally necessary to increase the rate of air change to 25 times per hour, particularly if this refers to a dining saloon, as will be dealt with presently.

Distribution and circulation of air in public rooms is of even more importance than in passengers' rooms. In the best ships and in best practice it is endeavored to arrange the inlets and outlets at ceiling level or on walls in alternative formation so that by the principle of thermosyphonic action, the air will be circulated in numerous sections and not in one large body; thus ensuring equable distribution and stable temperature conditions as far as is practicable.

At this stage it is important to stress the necessity for speed variation on fan motors aboard ship and why it is desirable. There may be anything from 100 to 200 fans on board a vessel aggregating from 200 to 600 or more BHP. and it is vitally important that speed regulation should be provided, especially when it is realized that from 50 to 75 per cent of these motors are running continuously day and night, summer and winter, except when the vessel is in port or laid up for overhaul.

Such enormous power and energy must be curtailed whenever possible and the value of speed regulation is obvious from the simple theory that if regulation of ⅓ reduction below maximum speed is provided in the motors, the fan law operates, that as power absorbed varies approximately as the cube of the speed, so a reduction of speed by ⅓ will reduce power absorbed by more than ⅔, and in addition will save approximately ⅓ of the steam required for air-heater batteries in winter work.

(e) Dining Saloons.

The dining saloon, like other large public rooms, has suffered from over treatment on the one hand and from lack of proper treatment on the other and the problem which confronts the ventilating engineer is to get the right balance.

At one time it was thought that all one had to do was to introduce large volumes of air and rely on the extract system operating in the adjacent kitchen and dependencies to remove the air via the service doors or large gratings in the dividing wall. This is definitely bad practice, as it produces excessive air movement in one direction and gives rise to complaints because of draughts and discomfort, in addition to being the wrong method entirely for the successful air movement so desirable and so necessary. Furthermore, it meant that kitchen extract fans had to be much larger than they need be to cope with this large volume of air, air which was not only "second-hand," but carrying the heat removed from the dining saloon and, therefore, unsuitable for creating cooling effect in the kitchen, where this is very necessary.

Nowadays in best practice the dining saloon is considered as a separate compartment and ventilated as such, but always bearing in mind that there must be some leakage of fresh air towards the kitchen, to prevent odors and fumes from the kitchen entering the saloon. The dining saloon must have its own fresh air and extract plant, but the extract is from 25 to 50 per cent less than the fresh air supplied, so that the excess may be available for the kitchen. Ventilated in the ordinary way by mechanical fresh air, a dining saloon should have not less than from 20 to 25 air changes per hour in maximum hot-weather conditions and mechanical extract at the rate of from 12 to 18 times per hour.

But it is always desirable to base the air changes upon the particular conditions of the dining room and not upon set air changes. This is where many go wrong, hence the dissatisfaction and the demand for air cooling, because every factor has not been considered in the first instance in determining the quantity to be used.

The following example illustrates the point:

What are the facts which ought to receive consideration, but which are very often ignored?

(*a*) The heat gains from the occupants of the saloon.

(*b*) The heat gains from electric lights, grilles and food.

(*c*) The heat gains from the exposed surfaces and walls, and from the machinery casings and kitchen services.

Only by determining the value of these factors in terms of heat can we determine the volume of air necessary to dissipate that heat, if not altogether, to at least a *few degrees above* outside conditions, for it will be appreciated that only an enormous supply of air can keep the conditions within the saloon to the level of outside conditions, and only air cooling by refrigeration can reduce the inside temperature to *below* the outside temperature.

And so the following facts and figures are given to illustrate the absolute necessity for treating the matter seriously and intelligently:

Cube of dining saloon ventilated = 115,000.
Heat of occupants—500 persons at 400 Btu. per hour each ..... = 200,000
Heat from electric lighting—40 Kw. at 3400 Btu. per hour ..... = 136,000
Heat from electric grilles—15 Kw. at 3400 Btu. per hour ..... = 51,000
Heat from food—500 meals at 50 Btu. per hour each.... = 25,000
Heat from structure by transmission and sun effect, approximate only ..... = 48,000

Total heat gains ..... = 460,000 Btu. per hour

Supposing the maximum air change provided is at the rate of 15 air changes per hour, therefore the quantity of air delivered to the saloon will be $115{,}000 \times 15 \div 60 = 28{,}750$ cubic feet per minute. Thus in the maximum conditions of heat gain in the dining saloon the temperature rise above atmospheric temperature will be

$$\frac{460000}{28750 \times 60 \times 0.02} = 13 \text{ degrees F., approximate.}$$

So that if conditions outside were in the region of 80 degrees F., as most commonly obtain in tropical waters, the inside temperature would be about 93 degrees F. and therefore intolerable.

To limit the temperature rise within reason, how much more satisfactory it would be to introduce air at 25 air changes per hour, and the result as follows:

$115{,}000 \times 25 \div 60 = 48{,}000$ cubic feet per minute circulated.

$$\text{Temperature rise } \frac{460000}{48000 \times 60 \times 0.02} = 8 \text{ degrees F.}$$

Assume outside dry-bulb temperature 80 degrees F.
Therefore temperature of air within = 88 degrees F.

This is a perfectly reasonable condition in the circumstances and represents the state of the air leaving the room, so that with the air entering at 80 degrees F. the actual mean temperature in the room would be about 84 degrees F. Another point worth mentioning is that whereas the public rooms on topmost decks are generally sheltered from direct sun effect, etc., by promenades and, therefore, can have large opening windows to admit air and natural light, down in the dining saloon there are no such facilities. The sides of the saloon are directly exposed to all weather conditions and temperatures, the portholes or sidelights are much smaller and, therefore, artificial lighting has to be greater than for other public rooms.

Electric lighting for dining saloons works out generally at about 5 watts per square foot of ceiling area as against 1½ to 2 watts in other public rooms, which makes a big difference in heat gains.

(f) Kitchens and Dependencies.

Most up-to-date vessels have now electrical cooking apparatus and it is estimated that for a vessel of world-cruising size, cooking equipment between 750 Kw. and 1000 Kw. is necessary. Taking into account the electric lighting as a further 10 Kw. it will be apparent that the heat which could be liberated is staggering.

For the sake of illustration, consider the smaller equipment:

$$\text{Total heat from elements and electric lighting} = 750 \text{ Kw.} + 10 \text{ Kw.} = 760 \text{ Kw. at 3400 Btu. per hour} = 2{,}600{,}000 \text{ Btu. per hour.}$$

Of this quantity it is assumed that approximately only ⅔ will be in use at any period and that 50 per cent of the cooking load will be dissipated in food, which would give us a figure approximately = 875,000 Btu. per hour.

This enormous quantity of heat set at liberty would result in a very high temperature rise, and if converted into the equivalent in air change in order to remove the heat and equalize the temperature with the outside conditions, would produce an impossible state of affairs in size and capacity of plant. And even to introduce sufficient air to keep the temperature rise to a limit of 10 degrees F. above outside conditions would demand somewhere about 100 air changes per hour. In theory this may seem quite easy and practicable, but it is altogether a different proposition when the facts are weighed up; the low ceilings, the very congested and limited available facilities, and the problem of distribution to avoid excessive draughts and cooling.

In actual practice 60 to 70 air changes per hour extract would work out quite well for the hottest part of the kitchen, reduced to 30 air changes for the dependencies according to their function and position. The amount of fresh air depends upon what is available from the dining saloon and should be made up by a quantity of entirely fresh air introduced direct to the kitchen, etc.

The important thing is to prevent the heat from spreading and if this is arrested at source by suitably designed ducts and orifices arranged so as to capture the wild heat and fumes direct at the ranges, grilles, toasters, salamanders, steamers, ovens, roasters, fryers, etc., there should be no difficulty about keeping the kitchen services in agreeable and satisfactory working condition.

(g) Cargo Holds and Stores.

Most large passenger vessels carry general cargo and stores in the holds and between decks, and although some ships have fan ventilation by means of screw-type fans mounted in coamings on deck or below deck, natural ventilation is the usual practice and the standard observed is generally 5 air changes per hour.

(h) Machinery Spaces.

There are so many sections and compartments allocated to boilers, engines, dynamos, auxiliary machinery, steering gear, bunkers (whether coal or oil), and so many different classes of machinery, which all call for special consideration.

In the smaller ships natural inlet and extract ventilators are considered sufficient for requirements with perhaps forced-draught fans for the boilers, but in the larger vessels the fresh-air ventilation is by mechanical means, and large natural ventilators, opening skylights and hoods or dummy funnels act as the extraction ventilation generally.

Air changes vary with the type of machinery but the following gives a general guide for various classes of engine rooms:

For steam reciprocating machinery—20 to 25 air changes per hour.
For turbine machinery—30 to 35 air changes per hour.
For internal combustion machinery—40 to 50 air changes per hour.

There are other important sections in a modern vessel worthy of mention, such as hospitals, laundries, hairdressing saloons, gymnasiums, swimming pool and Turkish baths, which are usually given special consideration in the way of heating and ventilation, and which combine to magnify the difficulties with which the ventilating engineer has to contend.

Air Conditioning.

In its most wide interpretation, air conditioning is not simply a reference to the improvement of comfort conditions in summer or the tropics, but in winter also, and it may be that this fact is not fully appreciated.

The air-conditioning installation, however large or small, is quite an expensive item and generally comprises a refrigerating plant, be it of CO_2, methyl chloride, freon or steam ejector type; complete with compressors, condensers, evaporators, circulating pumps, piping, etc.; to work in association with the air-conditioning unit with its spray chamber, eliminators and scrubbers, circulating spray pump, water tank, heating batteries and coils, piping filters; the fans and motors for circulating the cooled air, and the duct system all insulated, and finally the automatic control system, which is most essential and without which it would be utter folly to instal an air-cooling plant.

This briefly describes the installation; and the function of it, although simple, is worth mentioning in conclusion.

An air-cooling system is installed not primarily to reduce the outside air dry-bulb temperature, but also the relative humidity, which is known to be *the* oppressive element in tropical conditions. For example, in the Red Sea and Gulf of Aden, conditions have been noted by the Meteorological Office to be in the order of 100 degrees F. and 80 per cent relative humidity, and in the Pacific Ocean maximum conditions are about 90 degrees F. and 75 per cent relative humidity; and, of course, if it is intended that comfort is to be obtained, it will be the duty of a refrigerating plant not only to reduce the inside conditions when the vessel is passing through the Red Sea to, say, 95 degrees F. and 65 per cent relative humidity, but, if in the Pacific Ocean, to inside conditions of, say, 85 degrees F. and 60 per cent relative humidity.

Although this may represent a large refrigerating plant, usually based on the principle of cooling 25 per cent fresh air and 75 per cent recirculated air, it is appreciably much less than the load would be if 100 per cent fresh air were cooled.

The extraction of moisture from the outside air, or dehumidifying, as it is called, is the function performed by the cooled air contacting with the warmer air, and producing condensation in the conditioner casing. Moisture is thus captured which can be re-used for cooling purposes in such conditions, but in the operation of humidifying in winter time the reverse is the case, water being added to the air by evaporation, thus necessitating a certain "make-

up" of water from storage, which would require to be provided for in the vessel.

These are problems which are all involved in air conditioning.

A most important thing to consider is the system of air distribution, when the air has been cooled to be delivered to any room or saloon. Uniform draughtless distribution is much more essential in a system of this kind than with ordinary mechanical ventilation, due to the creating of lower temperatures and humidities; and, unless this is given very careful consideration, serious draughts are liable to be caused which would defeat the purpose for which air cooling has come into effect. Strong air movement by the ordinary system when the air is introduced at outside conditions, is not nearly so harmful as a smaller quantity of cooled air not properly distributed, and this is one thing which must be guarded against in the further development and advance of air conditioning in its application to ships.

It is to be hoped that as the study of heating, ventilating and air conditioning becomes more advanced, as applicable to ships, and as real as it is fascinating, so may results be achieved, which will ultimately prove of such benefit to those who live and travel on the high seas that it may no longer be said they do not compare favorably with the comfort conditions to be experienced and enjoyed in high-class buildings on land.

THE S.S. *EXPORTER.*

The description is of the first of four new freighters for the American Export Lines. It is reprinted from the September 23, 1939, issue of "The Nautical Gazette," 20 Vesey Street, New York, N. Y.

Many years of experience in operating ships in the Mediterranean traffic are represented in the design of four new vessels now being built for the American Export Lines, Inc., by the Bethlehem Steel Company's Shipbuilding Division at their Fore River Plant, Quincy, Mass. First of the quartet, the *Exporter,* was delivered to the owners in September to be followed by the *Explorer* and later the *Express* and the *Exchange.*

The four ships under discussion are part of the American Export Lines' replacement program, a schedule which calls for the building of ten new ships. Designs for the first four were prepared by American Export Lines, Inc., in collaboration with the United States Maritime Commission. Special heed was paid to the exigencies of the Mediterranean and Black Sea service, in which these ships will engage. The four are all mutually alike, so the word "Exporter" in this paper may be taken to include the other three as well.

The *Exporter* is of the shelter-deck type, presenting a fine and well-proportioned profile, with continuous sheer, a slightly raked stem and a transom stern. Principal dimensions and capacities of the ship are as follows:

Length overall—473 feet, 1 inch.
Length b.p.—450 feet.
Breadth moulded—66 feet.
Depth moulded to shelter deck—42 feet, 3 inches.
Depth moulded to 2nd deck—33 feet, 1½ inches.
Depth moulded to 3rd deck—24 feet.
Camber on shelter deck—7½ inches in 66 feet.
Deadweight—8875 tons.

Bale capacity—535,000 cubic feet.
Dangerous cargo in deck house—1750 cubic feet.
Cargo oil in fuel oil deep tanks—980 tons.
Fuel oil, including deep tanks—2050 tons.
Fresh water—360 tons.
Reserve feed water—340 tons.
Peak tanks, salt water—180 tons.
Sustained sea speed, fully loaded—16½ knots.
Steaming radius at sea speed—15,000 nautical miles.

Several special features have been included in the design of the *Exporter* and her three sisters. These specialties include a centralized ventilation system to provide forced circulation for four of the seven holds, crew accommodations for all hands in 'midship quarters with the latest conveniences, efficient electric cargo handling gear and, of course, complete fire-detecting and CO_2 fire-extinguishing apparatus for all holds and the machinery space.

Special interest attaches to the cargo-stowage facilities on the *Exporter,* owing to the fact that the four new ships were specially laid out with reference to the traffic in and out of the Mediterranean and Black Sea ports. In this service the outward cargo consists largely of machinery, manufactured goods and bulk grain, while the flow in the other direction is usually raw materials, including a good deal of tobacco, oil and ore.

With this service in mind, the designer has arranged that the deep tanks should serve a double purpose. On the outward trip they are filled with fuel oil, permitting the ship to fuel up in this country for the entire round trip.

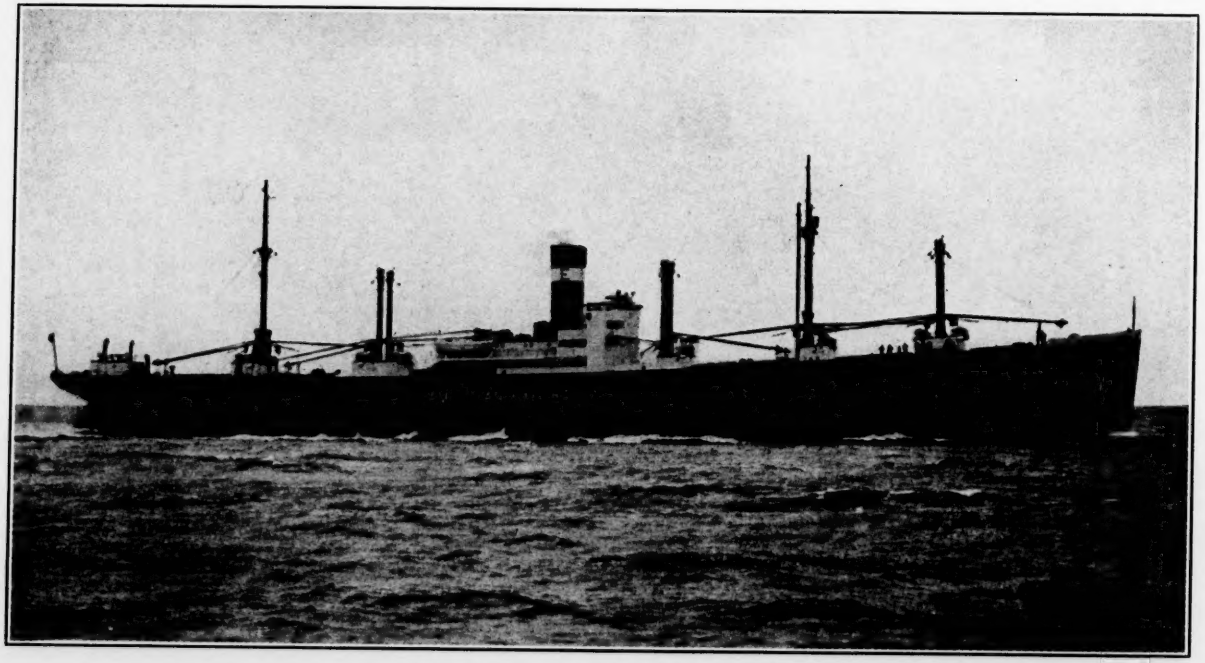
When the deep tanks are empty of fuel oil, they can then be made available, after a thorough cleaning, to carry bulk sulphur, olive, cotton seed or other vegetable oils.

Other attention to cargo is found in the installation of a "Cargocaire" ventilating system, to forestall condensation and its consequent damage to cargo. In essence this equipment consists of a dehumidifier through which all air circulating to the holds is passed. This is believed to be the first centralized system of its kind to be put on a new ship and its use is expected to reduce or eliminate difficulties through cargo condensation and damage. More detailed information concerning the functioning of this system was outlined in an article in "The Nautical Gazette" issue of May 6, 1939, by L. S. Andrews, Operating Manager of the American Export Lines, Inc.

The main power unit, built in Bethlehem's shop, is a cross compound turbine of the impulse-reaction type, with a normal rating of 8000 SHP. at 96 RPM. and a maximum output of 8800 SHP. at 100 RPM. The astern turbine develops 4500 SHP. at 70 RPM. This power unit drives a single propeller through a set of Falk double reduction gears. The turbine is designed to operate at a throttle pressure of 425 pounds per square inch at a temperature of 740 degrees F. and 28¾ inches Hg vacuum.

The high pressure turbine carries a two-row impulse wheel followed by reaction blading. Normal output is obtained with 90 per cent of the nozzle area. The rotor is of the drum type, a one-piece nickel steel forging. The impulse wheel nozzles are of stainless steel and of the built-up type, having machined steam passages to obtain high efficiency. Individual blocks are machined to the required shape and assembled in an annular groove in the casing.

There are fourteen impulse wheel nozzles arranged in four groups. One group contains seven nozzles and is controlled by the main throttle only. Each of the other groups is actuated by a nozzle control valve in addition



S. S. Exporter—American Export Lines.

to the main throttle. All nozzles are of the non-expanding type and have the same throat area. Sufficient combinations of nozzle control valves are available to insure efficient operation over a wide range of power.

The impulse blading is of stainless steel with root, skirt and blade machined from a solid bar. Root fastenings are of the dovetail type. Shrouding is riveted to the blade by tenons formed on the blade tips. Anti-rotation loss shields are fitted all around except in way of nozzles.

A balancing dummy is provided to partially neutralize the end thrust due to steam pressure. The residual unbalanced thrust is absorbed by a pivoted pad thrust bearing at the forward end of the turbine. The dummy is proportioned so the thrust bearing load will be moderate at all times.

The ahead low-pressure turbine is of the single flow, conical rotor type. Rotor and casing blading is of stainless steel with stainless steel binding wires brazed to the blade. The root fastening and method of installation is akin to the high-pressure reaction blading described above. No shroud bands are used in the low-pressure casing, but steam leakage is minimized by close radial clearances between blade tips and rotor or cylinder surfaces. And again as in the high-pressure unit, there is a balancing dummy to offset end thrust due to steam pressure.

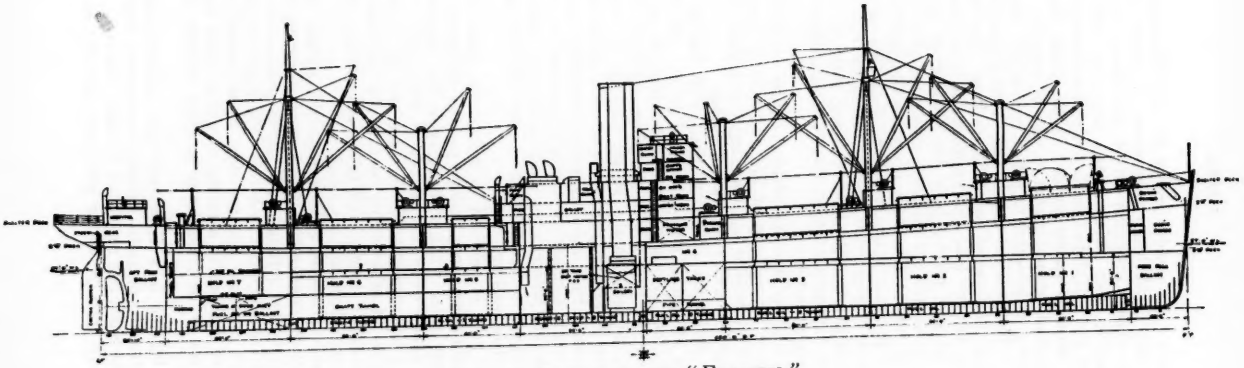
Incorporated in the low-pressure turbine casing is the backing-up turbine, designed to give 80 per cent of full ahead shaft torque at 48 RPM. of the main shaft. This turbine has two stages of impulse blading, the first with three and the second with two rows of blades.

Turbine bearing shells are of brass, lined with babbitt and lubricated through oil grooves located at both horizontal joints. Oil for the forward bearing is supplied from the thrust bearing housing, the oil grooves being left open at that end and closed in at the after end only. Oil baffles fitted at the bearing ends adjacent to the glands prevent oil leakage along the shaft. Gland packing is of the labyrinth type with radial clearances. The steam supply is regulated by a reducing valve controlled from the operating platform. Only a small quantity of steam is required to be supplied the glands from an external source when running at full power. When running steadily at reduced speed, provision is made for the use of auxiliary exhaust steam for gland sealing.

A Falk reduction gear is provided to reduce the speed between propulsion turbines and main drive shaft, making possible the use of efficient prime movers of high rotary speed while still satisfying the requirements for high propeller efficiency which entail low RPM. at the wheel. The gears are of the double-helical and double-reduction type and are so arranged as to allow the condenser to fit athwartship, beneath the low-pressure unit, permitting a short connecting trunk. All gears and pinions are dynamically balanced to 15 per cent above normal speed.

The pinions are each connected to their respective turbine through flexible couplings. These pinions engage high speed gears, which in turn drive their respective low-speed pinions through quill shafts passing through the high speed gear hubs and low speed pinion bores. The gears are cut on generating machines of high precision and are then lapped, tested and burnished. Pinions and gears are enclosed in a casing of welded steel construction, designed to afford access to the pinions and bearings without dismantling the entire assembly.

The main thrust bearing is a Kingsbury and is built integral with the bull gear. An electrically operated turning mechanism, working through a gear train, turns the shaft one revolution in eight minutes. A 1400-gallon gravity-flow tank feeds lube oil to the gears and bearings and then into a



General Profile of the "Exporter."

1200-gallon sump tank built into the foundation of the casing, and pumping arrangement of Worthington manufacture.

Steam is supplied from two Babcock & Wilcox single pass water tube boilers, fired by burners of the same make. (Two of the ships are, however, to be fitted with Todd burners.)

Each of the 73-ton boilers has an air heater, as well as superheater and de-superheater. No economizer is provided, however, the area of the air heater being deemed enough to reduce the stack temperature to 375 degrees at maximum load.

Each boiler has a heating surface of 5640 square feet, an air heating area of 3332 square feet and can generate 35,500 pounds of steam per hour at a working pressure of 450 pounds per square inch and a temperature of 750 degrees F. at the superheater outlet. Two forced draft fans deliver 40,050 pounds of air per hour to each boiler, either blower alone being able to supply the two boilers at a reduced volume. A two-stage feed water heater supplies water to the boilers at 300 degrees F., the height of the water in the boilers being controlled by a patented regulator in the main feed line.

The first stage heater operates on a pressure of ten pounds per square inch from the auxiliary exhaust and is able to raise 85,000 pounds of water per hour from 110 to 235 degrees F. It has a sub-cooler for cooling drains to 150 degrees F. The second heating stage operates on steam at 70 pounds per square inch bled from the main turbine and is capable of raising the temperature from the 235 degrees of the first stage heater to the 300 degrees which is then passed to the boilers.

The front and rear walls and furnace floors are lined with B&W Refractory material. Five Babcock & Wilcox decagon mechanical-atomizing oil burners, arranged for double-front forced-draft operation, will be installed on the boilers of two of the vessels.

The boilers and air heaters are double-cased, and part of the air for combustion is circulated through this casing to reduce heat loss by radiation and help maintain a cool fire-room. The boilers, superheaters and air heaters are completely equipped with mechanical soot blowers of Diamond valv-in-head type.

Mounted on two girders beneath the low-pressure turbine is the main condenser, of the single-pass type and built by Bethlehem. It has ¾-inch tubes, a total surface of 9533 square feet, and will maintain a vacuum of 28¾ inches at the turbine exhaust with a sea temperature of 70 degrees F. An electrically powered, worm drive, horizontal, centrifugal, single-stage Warren pump main circulator supplies water to the condenser.

A duplicate, Westinghouse two-step ejector removes air from the condenser, either pair of ejectors being adequate to service the condenser, leaving the other ejector for standby use. The capacity of each pair of ejectors is 30 pounds of dry air per hour.

There are two 160-gallon centrifugal pumps to move the condensate, one alone being sufficient for ordinary operation, the other as standby.

The main turbine, boilers and auxiliaries are all assembled in one machinery room amidships. This affords a compact and efficient unit which the engineer on watch can keep in hand easily from the operating station.

There are two main feed pumps of Warren make and a port feed pump, all steam turbine driven. All the other auxiliaries are electric Westinghouse motors. The ventilation blowers for the crew's quarters bear the Sturtevant nameplate. Cargo winches are by Lidgerwood, with Westinghouse motors.

Current for these various auxiliaries, windlasses, deck winches, etc., is furnished by three 150 Kw. General Electric geared turbo-generators. Two units together can supply the load, leaving the third for emergency. These turbines draw steam at full boiler pressure and exhaust into the auxiliary or main condenser at 28-inches Hg. It is affirmed that the generators can run at a 25 per cent overload for two hours without excess heating. For emergency service there is a 15 Kw. Diesel generator, with automatic cut-in.

In the wheel-house is the usual gyro compass, with three repeaters, gyro-pilot, course recorder, fathometer, and revolution tell-tale. There are three separate and independent telephone systems to provide communication between the pilot house and the after steering station, the steering motor room, the engine room, the chief engineer's cabin, the forecastle and the crow's nest.

Quarters for the crew are situated in the after shelter deck, the men being housed in two- and three-berth rooms. Officers are on the deck above. All accommodations are as near fireproof as possible and the bulkheads are of "Carey Core." Aside from the owner's suite, there are no facilities for the carrying of passengers.

On the maritime map "Ex" marks the spot of four fine American ships—*Exporter, Explorer, Express* and *Exchange.*

C-1 VESSELS OF THE U. S. MARITIME COMMISSION.

The abstract is from the "Pacific Marine Review" of September, 1939, published in San Francisco, Calif. It comments upon the salient design features of the class.

Four designs have been issued by the U. S. Maritime Commission under the general designation C-1, These four are specifically stamped:

C-1 AD, a shelter deck type of hull driven by Diesel engines;
C-1 AT, a shelter deck type of hull driven by steam turbines;
C-1 BD, a full scantling type of hull driven by Diesel engines; and
C-1 BT, a full scantling type of hull driven by steam turbines.

Common Features.

In the main, the general description of these hulls is the same for all four types and we will here set down the features that are common to all of them.

The hulls are of steel with single screw, cruiser stern and raked stem. Two complete steel decks are fitted all fore and aft. A third deck below the second deck is fitted forward of the machinery space. Aft of the machinery space a flat is carried across the holds at the level of the top of the shaft tunnel.

The forward end of the deckhouse is exactly amidships and the forward machinery space bulkhead is seven frames aft of amidships.

Accommodations for passengers, officers and crew are all in the deckhouse amidships. As will be noted in the general arrangements plans reproduced herewith, this deckhouse has two deck levels above the weather deck and surrounds the machinery casing.

On the second deck level in way of machinery casing are located: on the starboard side the galley, crew's mess and lounge, a pantry, petty offi-

cers' mess and lounge, and stores; and on the port side a room for CO_2 bottles for fire extinguishing system, the refrigerated stores, the hospital and the laundry.

At the weather deck level are located accommodations for the seamen, oilers, wipers, boatswain, carpenter, electrician, steward, messmen, cadets, first assistant engineer, second assistant engineer, third assistant engineer, junior third assistant engineer, and the ship's office.

The boat deck is fitted with accommodations for the chief engineer, the deck officers, the radio operator and eight passengers. A commodious dining room and lounge is installed amidships at the forward end of this deck, flanked by two staterooms on each side. Each of these four rooms houses two passengers and each room has a private shower and toilet. The dining room has a large pantry adjoining. A room on this deck is assigned for the emergency generator and control station. There are two lifeboats hung on davits served by electric winches. Each of these boats has a capacity to take 59 persons. In other words, 10 more than entire number of persons normally on board can be accommodated in each boat.

On the bridge deck are the captain's accommodations, the wheel house, the chart room, the radio room, a spare stateroom with shower and toilet, and a fan room.

The boatswains stores are located forward of the forward collision bulkhead, and the carpenter shop and paint room aft of the after peak bulkhead.

There are seven watertight bulkheads dividing the ship into eight spaces from forward aft, as follows: The fore peak, No. 1 hold, No. 2 hold, No. 3 hold, machinery space, No. 4 hold, No. 5 hold, and the after peak.

Hatches for Nos. 1, 2 and 3 holds forward are served by 9 booms on two pairs of king posts and by 8 electric cargo winches. The beam across the tops of the forward pair of king posts carries at its center a pole mast from which the radio antenna runs aft to a similar mast on the pair of king posts aft which serve the hatches for Nos. 4 and 5 holds. At these after king posts there are four booms and four electric cargo winches.

The pole masts are demountable and the king posts are designed to pass under the bridges of the Manchester ship canal with these poles lowered when the hulls are down to a draft of 19 feet.

Twelve of the cargo booms are of 5 tons working capacity. One heavy lift boom on the after side of the forward king posts and serving hatch No. 2 is of 50 tons capacity, and another on the after side of the after king posts and serving hatch No. 5 is of 25 tons capacity.

All booms are to be of sufficient length so that when topped to an angle of 45 degrees they will have an outreach of 18 feet over the side of the ship.

In addition to the deck hatches on all types of C-1 hulls side ports are provided in way of the upper tween decks in holds No. 2, No. 3 and No. 4.

All of the weather deck hatch covers are to be of the "Tutin" type, which eliminates the use of strong backs and wood covers and stows at the end of hatch combing, leaving the deck clear for cargo handling.

A forced system of ventilation is to be installed for all cargo spaces, and rooms are provided in the upper tween deck spaces for installation of electric blowers for this purpose. In this connection the Maritime Commission states that it "has in mind a system of hold ventilation recently introduced, called 'Cargocaire,' and earnestly invites the attention of shipowners to this important question."

A complete smoke detection and CO_2 fire smothering system will cover all cargo spaces.

The mooring equipment and fittings have been arranged to suit requirements of canal authorities. The electric windlass forward has two attached

warping gypsey heads, and there are two electric capstans aft. Bitts, chocks and fair leaders are installed in sizes and locations to meet all warping and mooring requirements.

Full radio equipment of the most modern type will be installed, including radio direction finder. A master gyro compass and several repeaters, a gyro helmsman, a Fathometer and searchlights will be included in navigation equipment.

All furniture, all joiner work, all partitions in crew's and passengers' accommodations will be of incombustible materials. In the design especial attention has been given to provide adequate lighting and ventilation. Steam heating is provided in all quarters.

The galley is a modern, all-electric kitchen trimmed in stainless steel and fitted with sanitary tile flooring.

So far this description has covered those features that are the same on all four C-1 designs. We will now look at the differences.

Hull Differences.

In the shelter deck type of hull the bulkheads between cargo holds are made watertight only up to the second deck, while in the full scantling type these bulkheads are of watertight construction up to the weather deck. Since the deck which tops the watertight bulkheads is the free-board deck, for classification and load line purposes it is evident that the full scantling type can be loaded deeper and hence carry a heavier deadweight cargo than the shelter deck type.

The hull of the full scantling type must therefore be made stronger than that for the shelter deck type, and the table of comparative characteristics herewith shows the additional weight of steel built into the hull for strength purposes. It will be noted that for a total of 200 tons additional weight built into the hull there is a gain of 1540 tons cargo dead-weight capacity in the case of the turbine-drive ships and of 1575 tons in the case of the Diesel-drive ships. This full scantling type will therefore be of great advantage to those operators handling mostly weight and not volume tonnage.

It will be noted also that there is a very marked increase in net measurement tonnage in the full scantling type. This increase, approximating 2000 tons, becomes a very important factor in the operating expense of a ship, particularly in those routes transiting canals and calling at many harbors. Most charges against the ship are based on net measurement.

Another advantage of the full scantling type as designed by the U. S. Maritime Commission is a large hatch forward. The following table shows the comparative sizes:

Size of Hatches.

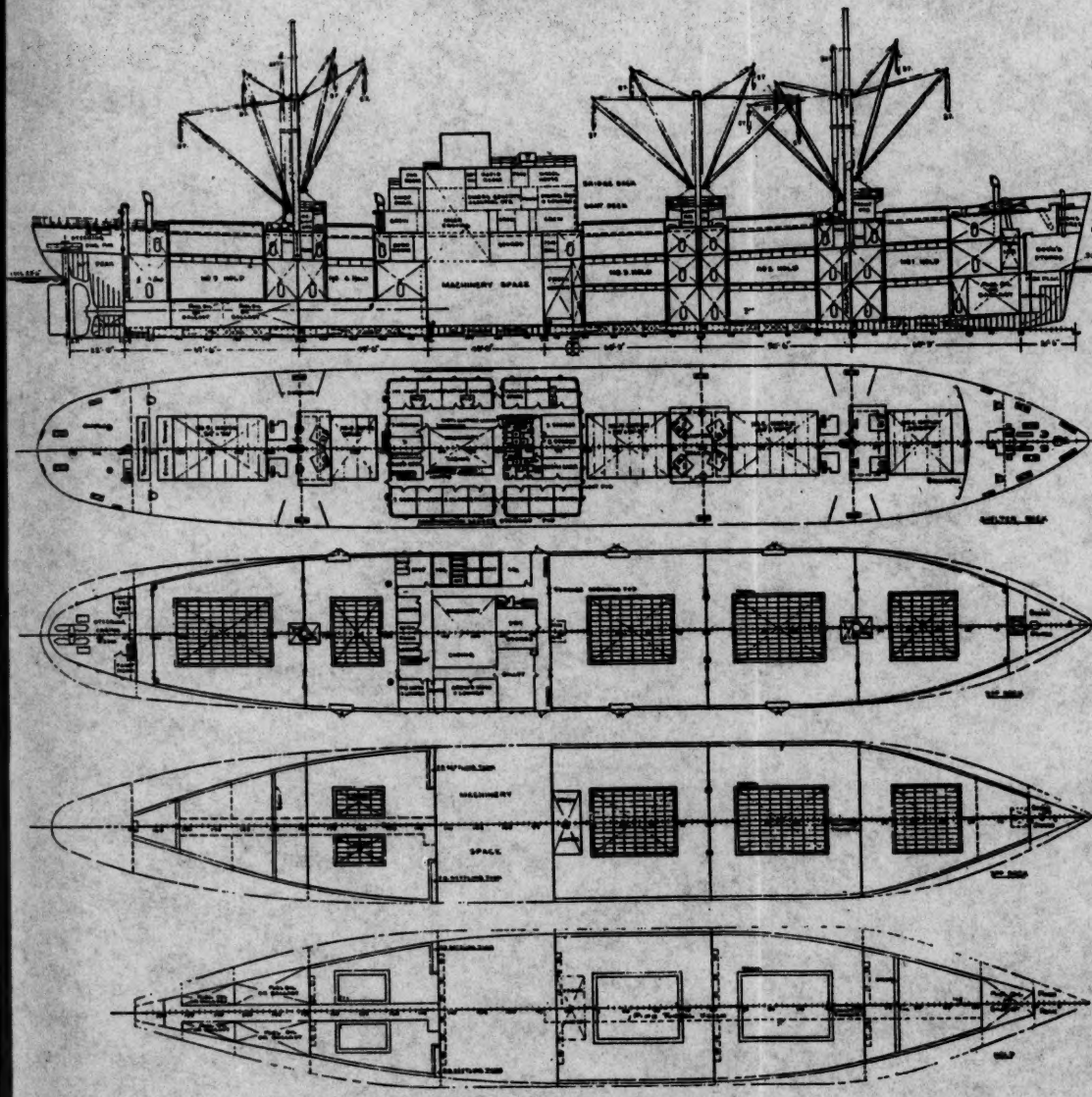
Hold	*Shelter Deck (feet and inches)*	*Full Scantling (feet and inches)*
1	24–0 × 24–9	24–0 × 27–0
2	24–0 × 33–9	24–0 × 42–9
3	24–0 × 31–6	24–0 × 24–9
4	24–0 × 18–0	24–0 × 18–0
5	24–0 × 36–0	24–0 × 36–0

This long opening in No. 2 hold will be of great benefit in the economic handling of some cargoes.

The spacing of bulkheads governing the fore and aft length of holds is decidedly different in the two types. Lengths of each hold in each type is as follows:

C-1 Shelter Deck Type Design.

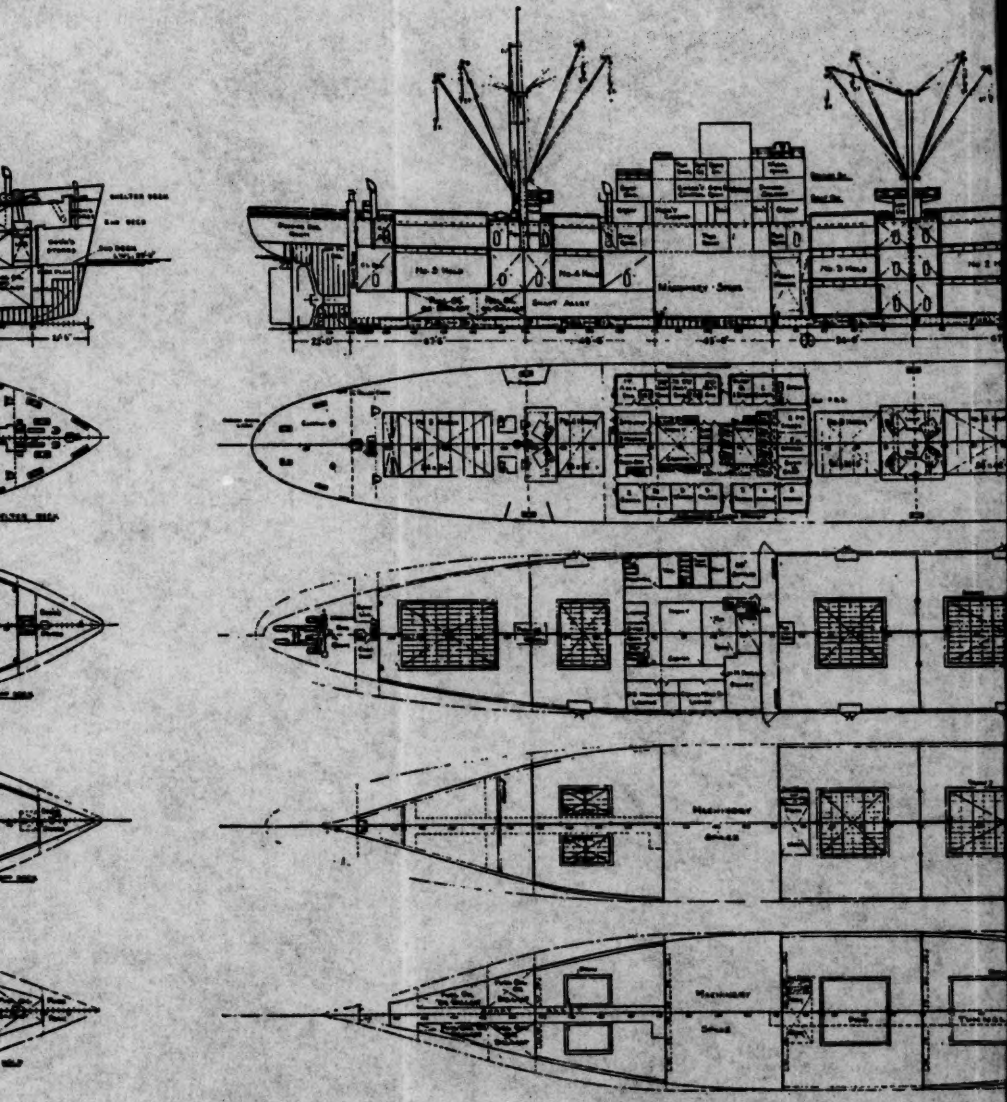
Inboard Profile and General Arrangement Plans.



This type is designed for routes having a large proportion of volume cargo and package goods. It gives a large cubic capacity on a low net measurement tonnage.

C-1 Full Scantling Type Design.

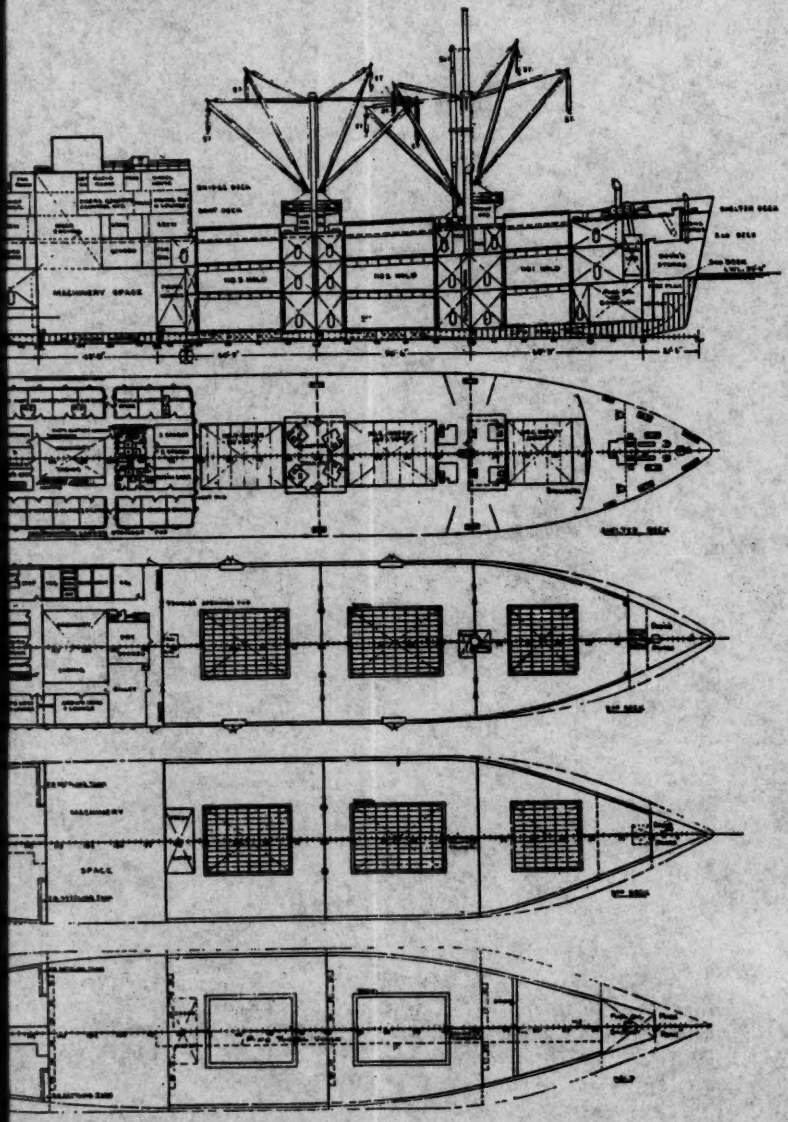
Inboard Profile and General Arrangement P



The full scantling design deeper draft and consequently a gre
carrying capacity. Since the bulkheads in this type
tight to the weather deck, no tonnage openings are allo
'tween decks and so the net measurement is comparativel

C-1 Shelter Deck Type Design.

ND Profile and General Arrangement Plans.



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goods. It gives a large cubic capacity on a low net
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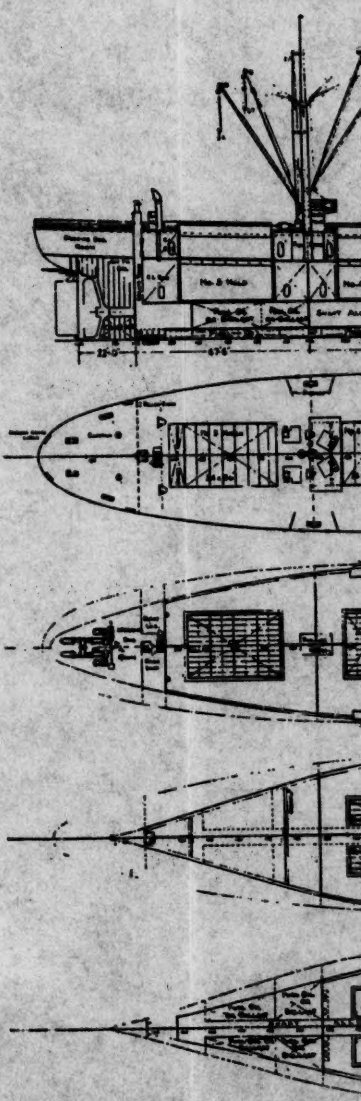

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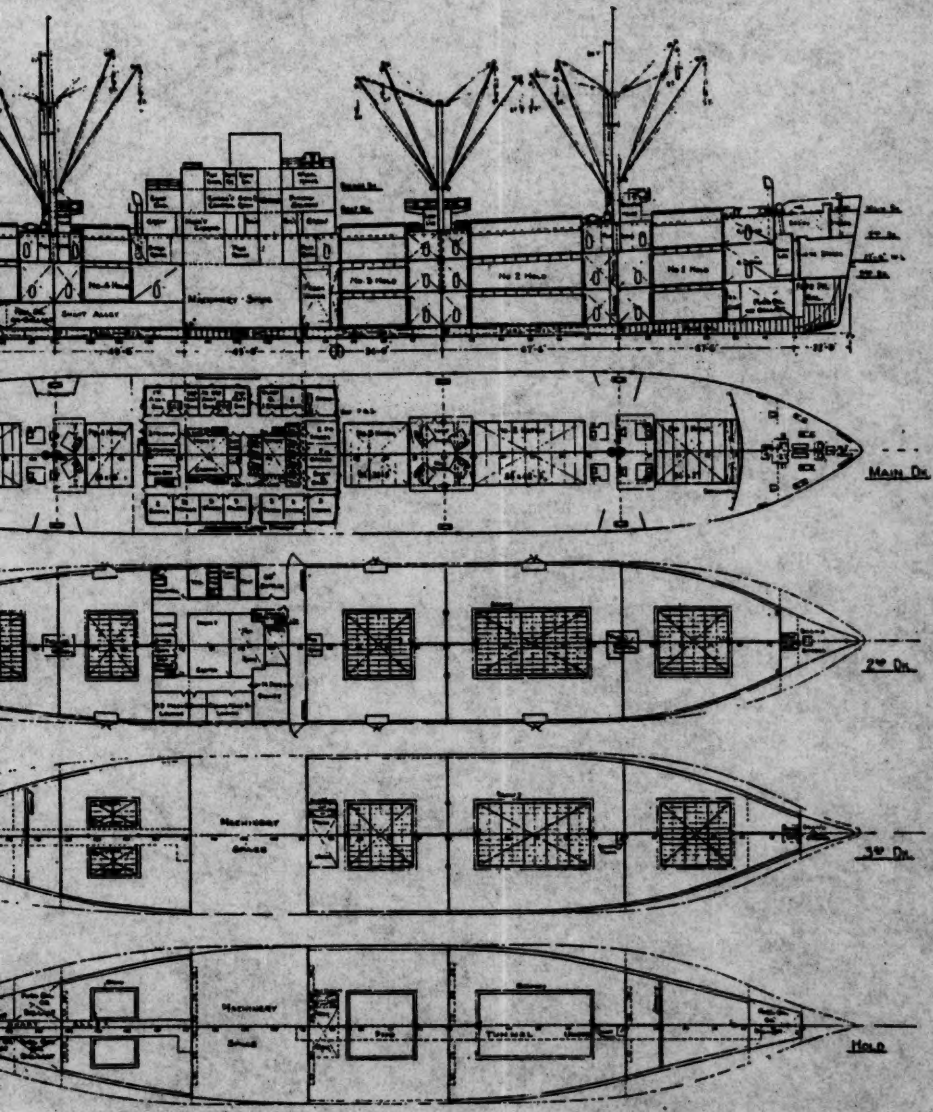
C-1 Full Scantling Type Design.

Inboard Profile and General Arrangement Plans.



The full scantling design deeper draft and consequently a greater dead-weight carrying capacity. Since the bulkheads in this type must be water-tight to the weather deck, no tonnage openings are allowed in the upper 'tween decks and so the net measurement is comparatively large.

Hold	*Shelter Deck (feet and inches)*	*Full Scantling (feet and inches)*
1	65–3	67–6
2	58–6	67–6
3	60–9	54–0
4	49–6	49–6
5	67–6	67–6

GENERAL CHARACTERISTICS OF C-1 DESIGNS.

Characteristics	*Shelter Deck Turbine*	*Shelter Deck Diesel*	*Full Scantling Turbine*	*Full Scantling Diesel*
Length Overall (approximate), feet and inches	413–0	413–0	416–0	416–0
Length Between Perp's, feet and inches	390–0	390–0	395–0	395–0
Beam Molded, feet and inches	60–0	60–0	60–0	60–0
Depth Molded Shelter Deck, feet and inches	37–6	37–6	37–6	37–6
Draft Molded Loaded, feet and inches	23–6	23–6	27–6	27–6
Deck Height, 2nd to Shelter, feet and inches	9–3	9–3	9–6	9–6
Deck Height, 3rd to 2nd, feet and inches	10–0	10–0	10–6	10–6
Sea Speed at Loaded Draft, knots	14	14	14	14
Shaft HP. Normal	4000	4000	4000	4000
Normal Crew	43	41	43	41
Passenger Capacity	8	8	8	8
Gross Measurement, tons	5028	5028	6750	6750
Net Measurement, tons	2820	2820	4800	4800
Weights: Hull Steel, tons	2180	2180	2365	2365
Outfit, tons	768	768	767	767
Engineering tons	500	600	500	600
Margin, tons	152	152	168	168
Total Built Weight, tons	3600	3700	3800	3900
Fuel Oil, tons	889	653	889	653
Crew and Stores, tons	35	35	35	35
Fresh Water, tons	336	272	336	272
Dead-weight Cargo Capacity, tons	6240	6440	7815	8015
Loaded Displacement, tons	11100	11100	12875	12875
Bale Cubic Capacity, feet	451288	449928	450146	448786

Figures for this table are taken from the "General Description of C-1 Designs," issued by the U. S. Maritime Commission. The figure for fuel weights carried is based on 10,000 nautical mile cruising radius and contemplates using about ½ of the fuel capacity in the case of the Diesel ships and a little over 60 per cent in the case of the turbine ships. In the case of the full scantling type hull with Diesel drive the figures issued by the Commission contemplated fuel and water for 12,000 miles. We have taken the liberty of reducing these weights to those necessary for the 10,000-mile range so as to give a comparison on a more equable basis. Using the total fuel oil tank capacity fitted, the turbine drive ships would have a cruising radius of approximately 16,000 miles and the Diesel-drive ships approximately 21,000 miles, both at 14 knots speed.

Diesel Power Plant.

The specifications for the Diesel drive for the C-1 ships call for two directly reversible Diesel engines, each connected through hydraulic or electromagnetic slip couplings to one of the pinions of a single reduction gear set, the slow speed gear of which is directly connected to the propeller shaft.

These engines must deliver a total of 4000 shaft horsepower on the propeller shaft when that shaft is turning 90 revolutions per minute and the engines are running at their normal rated speed. They must be capable of maintaining operation under a continuous overload of 10 per cent and of maintaining operation for 2 hours at 25 per cent overload.

This propulsion unit will be controlled from a single operating station. The controls will be so arranged that both engines or either of them can be started, stopped or maneuvered, and both couplings or either of them connected or disconnected from the single station.

Electrical load will be carried by Diesel-driven generating sets of adequate capacity.

Exhausts of both main and auxiliary engines are used in a waste heat boiler to provide steam for heating quarters, heating fuel oil, and other purposes.

Estimates based on data from towing models of this hull show that with moderate fouling of bottom and adverse weather conditions a loaded sea spead of 14 knots can be maintained with 3750 shaft horsepower. Since the plant can deliver 4400 shaft horsepower continuously, or 17 per cent more than necessary to maintain sea speed, there should be no difficulty in keeping schedules with these cargo liners.

It is announced that the consumption of fuel based on the use of 3750 SHP. and on oil of 19 API. gravity will be 118 barrels a day. This works out at approximately 0.4 pounds of oil per shaft horsepower hour for all purposes and is attainable on a continuous operation basis with a modern Diesel engine plant.

Steam Turbine Drive.

In the turbine jobs steam will be generated by two modern marine type water tube boilers with a gage pressure of 450 pounds per square inch and a temperature of 750 degrees F. These boilers will be installed in the machinery space forward of the propulsion unit. They will burn oil under forced draft and will deliver steam to a cross compound, high speed modern marine type turbine. Double reduction gearing of the most efficient type will connect the turbine rotor shafts to the propeller shaft and deliver thereto 4000 shaft horsepower at 90 revolutions per minute.

These turbines must be capable of maintaining operation under a continuous overload of 10 per cent, and must be capable of operating at 25 per cent overload for 2 hours.

Most auxiliaries are electric and the electric light and power load will be handled by steam turbine generating sets.

It is stated that the consumption of fuel based on 3750 shaft horsepower and oil of 15 API. gravity will be 166 barrels a day. This figure seems to work out at 0.628 pounds per shaft horsepower hour for all purposes.

THE VOITH-SCHNEIDER SYSTEM OF PROPULSION.

A new type of propulsion for ships has been developed to the point where marine engineers must give it due consideration. For several uses the Voith-Schneider propeller appears to possess features superior to the screw propeller,

and, for good measure, it eliminates need of a rudder. The following abridgement is of a paper prepared by Captain E. C. Goldsworthy for presentation before Section G of the British Association at Dundee, September, 1939. It is reprinted from the September 15, 1939, issue of "Engineering," published at 35 Bedford Street Strand, London, England.

In contemplating the new system, the following historic background is of great interest: The Fowler Wheel propulsion was installed in the U. S. S. *Alarm,* of 700 tons, built at the Brooklyn Navy Yard in 1874 from designs by Admiral D. D. Porter, U. S. N. This vessel had a bow gun which could only be fired dead ahead. Thus it was necessary that the gun be trained in azimuth by swinging the ship. In order to meet conditions where an ordinary rudder would be useless, Admiral Porter decided to give the horizontal feathering wheel a trial.

The Fowler Wheel was composed of rectangular paddles. It was wholly submerged and situated just abaft the stern-post in the place occupied by the ordinary single screw. It received its rotary movement from its vertical shaft actuated by a crank in the vessel's overhanging stern. Each paddle was attached to a movable vertical axis supported on two fixed arms radiating, one directly over the other, from the central vertical shaft. The central shaft also carried a movable horizontal eccentric whose strap deflected the paddles through articulated rods. The position of the eccentric, and hence the deflection of the paddles, was actuated by a mechanism on deck under the immediate control of the conning officer. Without changing either the direction or the speed of the engines, the vessel could be propelled, steered, backed, turned on its axis, or maintained in position.

When applied to the *Alarm,* the horizontal feathering wheel fully realized its promises in regard to its capacity to maneuver the vessel. Its failure was in the poor propulsive efficiency derived, probably, from inefficient paddle sections. Later, to obtain greater speed, the Fowler Wheel was removed and a Mallory steering and propelling screw was installed.

A picture of the original Fowler installation is shown in the frontispiece.

Ten years ago, in 1929, the first Voith-Schneider propeller was fitted and demonstrated in the launch *Torqueo,* the propeller having a blade-orbit diameter of 800 millimeters and being driven from a 60-HP. petrol motor. Today, there are 120 ships fitted with Voith-Schneider propellers, operating in most countries of the world and in powers up to 2 by 2200 HP. with propellers of 2600 millimeters blade-orbit diameter, driven by steam, Diesel engines and electric motors. The results of the *Torqueo* proved beyond any doubt that a third system of propulsion had been added to the paddle and screw for mechanically powered ships. Furthermore, a method had been found whereby the ship could be propelled and controlled by the propeller alone, provided power was available to turn it in one direction.

Propulsion demands (*a*) the best efficiency possible for the ship under consideration; (*b*) good ship-maneuvering properties; and (*c*) simplicity of machinery, due consideration being given to the first cost and running costs. Good propulsion calls for the proper swept area of the propelling unit, from which we see that the large slow-running screw has undoubted superiority in deep-draught vessels, for, except in the heaviest seas, it is completely immersed and always doing its allotted work. The paddle, being designed for a certain immersion, is relatively inefficient in a seaway, since the water level at the

paddles is not constant and the thrust is impaired. In shallow water, however, the draught of the vessel would necessitate a small-diameter screw running at comparatively high revolutions, giving inefficiency of propulsion, particularly if the vessel is to be used for towing purposes. Under similar conditions, the paddle is better, in that a large swept area at constant immersion is given, which, combined with low revolutions, makes for good propulsive efficiency. Thus, with slow-running steam engines the paddle vessel has high efficiency, reasonable maneuverability and simplicity of machinery, with relatively low first cost. The under-water hull can be given fine lines and there are no appendages aft, such as bossings, shafting, or A brackets to reduce the hull efficiency.

With the advent of the Diesel engine, paddle-ship owners were anxious to obtain the advantages which this prime mover gave. The saving in weight would help in the draught, and thus add to the utility of the ship; the space gained in the engine room and the elimination of the boiler room and bunkers would increase the passenger or cargo accommodation; the ship would be cleaner, the engine room staff reduced and there would be a considerable reduction in running costs per mile. The problem was complicated in that it was necessary to bring down the relatively high speed of the Diesel engine to a shaft speed between 40 and 50 RPM. This has been done by mechanical reduction gear or by the use of electric generators and motors. The disadvantages of either mechanical gearing or of the electric drive for Diesel-engined paddle vessels are the added complication of the machinery, the relatively high first cost and the loss in transmission through the gears or electricity, which in the latter, with direct current, may be up to 20 per cent. It is, perhaps, because of the above that neither of these systems has been adopted to such an extent as the technical qualifications merit, with the result that many owners still prefer the steam engine. The Voith-Schneider propeller brought about a radical change in thought for vessels of limited draught, in that it gave all the desired features for such vessels in one complete unit and was applicable to Diesel, steam or electric drive.

Theory and Design.—The Voith-Schneider propeller, shown in Figure 1, consists of a number of vertical blades of aerofoil section rotating in the horizontal plane. These blades are spaced symmetrically about a rotating disc or runner wheel in an opening of the hull bottom and flush with the latter. The blades can be made to perform a swinging motion around their axis, and the law governing the blade movement is illustrated in Figure 2. The normals to the blade profile must all, and at all times, intersect at a point N within the blade orbit, this point being off center transversely to the thrust direction. The farther the point N is moved, the greater the pitch of the blades, and consequently, the thrust, until the limit at which full power is developed. If the point N is at dead center the blades will revolve and give no thrust, but with an increase of thrust the ship's speed will increase without any change in the speed of the engines. It is important to note, therefore, that the Voith-Schneider propeller is of variable pitch. By moving point N to the opposite side, through the center and beyond it, a thrust in the opposite direction is given and the blade profiles move in a similar but opposite manner to that for ahead thrust, there being still no change in the speed or direction of the engine or propeller. Point N can also be swung round the propeller center, so that the thrust direction can be varied, thereby steering the ship with the propeller and making it possible to swing her without any movement ahead or astern. The movement of the blades can be compared with a person sculling a boat with one oar at the stern, where the oar moves in a double circular orbit as if there were two Voith-Schneider propellers with one common blade. The

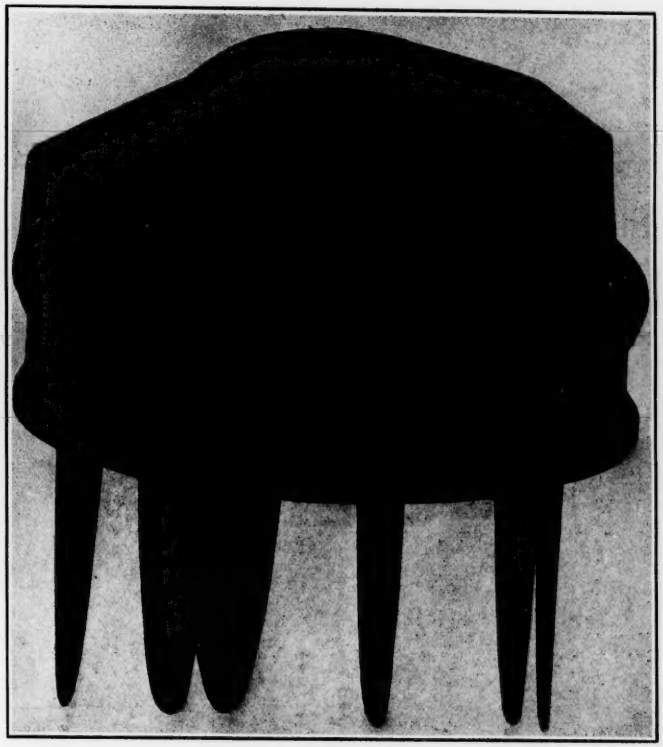


FIGURE 1.

Fig. 2.

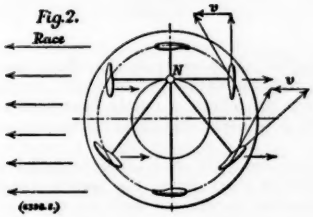


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Fig. 3.

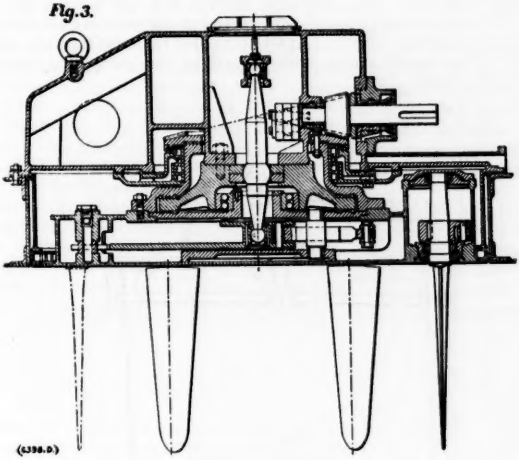

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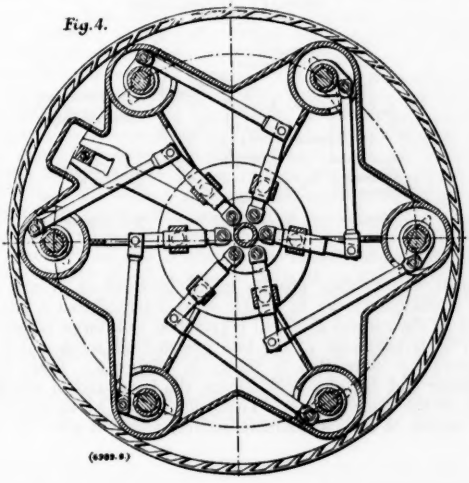
Fig. 4.

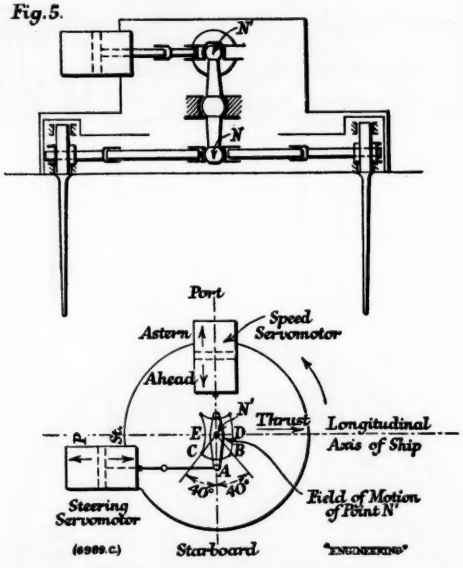


(1398.6)

Voith-Schneider propeller alone controls the ship's movements, unlike the normal vessel, which requires variability of engine speed, reversible engines, and rudder. With twin propellers, a purely lateral displacement of the ship can be obtained, which is of particular value to floating cranes and other such craft.

The present design of the Voith-Schneider propeller is fundamentally the same as the first propeller tried out in the launch *Torqueo,* built for J. M. Voith in 1929. Subsequent experience with all types of ships operating on lakes, rivers and at sea has brought about certain refinements. Originally, the propeller was built with hydraulic control, but, some six years ago, this was altered to mechanical control, still retaining the pressure-oil servo-motors for the central control column. Apart from this major alteration, there have been only minor modifications with regard to the pump, the bearings and seatings of the blade shafts.

Fig. 5.



The normals to the blade profiles which intersect at N are, in practice, replaced by a linkage, shown in Figure 4, so designed that a relatively small displacement of the control disc will correspond to a large eccentricity of the point N. The arrangement of the two pressure-oil servo-motors, by which the blade motion is controlled, is shown in Figure 5. These servo-motors act on the upper end, N', of a double lever, the lower end of which moves the control disc of the blade linkage. The point N can be universally displaced within the outline of an approximate square, and will give all the required

variations of speed and thrust direction. At full speed ahead (N at A), the blade position can be altered by about 40 degrees, allowing sharp turns to starboard, B, or port, C. If N′ is at D or E, the ship has no speed of advance, but a rudder angle of 90 degrees, and turns, with full power, on the spot. The speed servo-motor is controlled from a lever on the bridge and the steering servo-motor from a small handwheel, also on the bridge. This arrangement is similar to that used for the control of screw-propelled vessels and does not, therefore, present any strange features to the officers on the bridge.

The steering capacity of the Voith-Schneider propeller is considerably greater than that of the normal ship with a rudder. This is due not only from the turning of the thrust direction, which would probably give no more improvement than a ship at full speed, but from each individual blade which, when it is displaced from ahead position, produces large forces with components athwartships, so that each act in a similar manner as a small rudder at high speed. Another feature of the Voith-Schneider ship is the course stability when the ship has a good length of keel and normally disposed propellers. This good stability is probably due to the horizontal rotation of the propellers, which, combined with a properly designed stern, flattens out the wake to a broad, smooth surface.

No form of propulsion will give of its best unless the ship's hull is designed for that specific drive, allowing the proper flow of water to and from the propeller. With the Voith-Schneider drive in shallow-water vessels it is possible to use less draught and so increase the utility of the ship or for a given draught to have a larger swept area, thereby increasing the pull. On the other hand, with a deeper-draught vessel, the Voith-Schneider propeller can be placed farther below the water line than the screw propeller. This will be of advantage in rough seas, since the Voith-Schneider propeller will tend always to keep fully immersed. This is amplified by the fact that the race of the Voith-Schneider propeller sticks to the hull, so that when the stern lifts the water tends to rise with the stern, thereby giving continuity of thrust and control of the vessel and better speed in bad weather. The absence of all appendages, such as shaft brackets, bossings, stern frame and rudder, ensures a smooth and undisturbed flow of water to and from the propeller. This is not possible with the screw propeller, since the various appendages give irregular entrance velocity at various points of the blade-tip circle, which leads to loss of efficiency.

The mechanical features of the propeller are shown in section in Figure 3. The pinion shaft (above propeller on right of center) has self-aligning bearings, and on this shaft, operated by a chain, is the oil pump supplying the servo-motors at a relatively high pressure of between 160-280 pounds per square inch, depending upon the size of the installation and a pressure between 10 and 30 pounds per square inch on the lubricating system. The oil system is totally enclosed, the propeller housing being filled with oil to the underside of the main roller bearing and connected with discharge and suction pipes to an oil tank situated alongside the propeller. Oil channels are fitted, running to all the bearing parts situated above the oil level, so that a constant supply of oil is present as soon as the propeller starts up. The motion of the horizontal shaft is translated to the vertical drive through a spiral-bevel gear, and such gears are suitable up to powers of, perhaps, 3000 HP. to 4000 HP. There are ships in service with this form of drive with more than 2000 HP. per shaft. Above these limits it is necessary to employ electric drive with the motor placed directly above the propeller. The great advantage here is that alternating current can be used, since the propeller is of constant speed, thus giving simplicity of control gear and reducing first

cost. An interesting example of such an application is the H. A. P. A. G. Company's *Helgoland*. This vessel has turbo-electric drive, each motor being 2000 shaft horsepower, situated directly above the Voith-Schneider propeller, with a flexible mechanical coupling between the gears and the running part to avoid the possibility of shocks being transmitted to the motor.

The servo-motors are spring-loaded and are operated through the pilot valves, which, in turn, are controlled from either the speed lever or steering wheel on the bridge. With a twin-propeller installation, the servo-motors are harnessed together so that the propellers act as one unit, although turning as a rule in opposite directions. They can be deharnessed for athwartships movement by fitting an additional speed lever on the bridge. The connections from the bridge to the servo-motors are normally by rod and chain, but hydraulic and electric controls have also been fitted. The servo-motor pistons operate on the top end of the central control arm, which is held rigidly in position in a ball joint some two-thirds of the way down. The bottom end of the control arm fits into the control collar, which corresponds to point N, and is displaced according to the movement given to the speed lever or steering wheel. The amount of thrust given to the blades is directly proportional to the magnitude of the displacement of the bottom of the control arm from which the rods and levers connect to each blade shaft. Many parts of the linkage are identical and interchangeable. All joints and moving surfaces are bronze bushed. There is a main ball-bearing between the standing and rotating parts, and a main thrust collar with white-metal bearings.

The runner wheel is circular and has a clearance of about ¼ inch with the ship's hull. On the inside of the runner wheel are vanes which throw out any water and keep it out while the propeller is operating. When the propeller stops, the water will naturally rise between the casing of the runner wheel and the ship's well, taking up its normal water-line level. To keep this water out of the propeller, two spring-loaded carbon-ring packings are provided, with drainage channels to the ship's bilges. The packings are kept tight with grease and provision is made for this purpose on the propeller housing. An additional carbon-ring packing with a covering labyrinth ring is provided to stop centrifugal splash oil from the gear wheel falling out into the clearance channels and so into the bilges.

The blades are made either of phosphor-bronze or forged steel, depending on the horsepower and requirements of the owners. The shafts are tapered and firmly scured in a completely enclosed housing, with needle or roller bearings on the upper and lower parts. The lower bearings are fitted securely into the bottom of the runner wheel and the upper bearings into the top of the blade shaft-pots. In shallow-draught vessels a single spring-loaded chrome-leather cup is sufficient to retain the oil and keep the sea water out, while in the deeper sea-going vessels a double seal is given. The casing and runner wheel are of steel and electrically welded, the strength of materials naturally varying with the power and size of the propeller, while stainless steel is being increasingly used for the runner wheel in sea water. The installation is simple, the propeller being shipped as a complete unit and bolted to the top flange of a circular foundation well, which is an integral part of the ship's structure, connected to the hull, floors and frames. The pinion shaft is coupled to the engine shaft, the control rods from the bridge connected to the servo-motors, and the oil pipes to the tank.

Tank experiments and the studied results of the many ships in service clearly indicate the following advantages to be derived from the use of the Voith-Schneider propellers. The propulsive efficiency of the Voith-Schneider propeller is comparable with a good screw and properly designed paddle. In comparatively shallow-draught craft, therefore, the Voith-Schneider

propeller is superior to the screw, owing to its increased swept area. It also has the advantage over the paddle in rough weather and in its adaptability for either steam, internal-combustion engine or electric drive. The maneuvering capabilities of the Voith-Schneider ships are superior to those given by any other form of propulsion, which, together with the uni-rotational engine and propeller, and bridge control, constitute vital safety factors for vessels operating in crowded and restricted waters. The machinery installation as a whole is simple, in that rudder and steering gear are eliminated, reverse and reduction gears are not needed, and with direct drive, apart from the engine and propeller, only a shaft coupling is necessary. Since the thrust is taken up in the propeller and transmitted direct to the hull, no thrust block is required. The overall cost of the Voith-Schneider ship is comparable with the screw-propelled vessel in moderate sizes and power, while experience has shown that the average running costs are in keeping with other forms of drive. It would be absurd to claim that the Voith-Schneider propeller is suitable for all types of vessels, but it may be claimed to have decided advantages over the screw or paddle in certain types, while there are border-line cases which must be decided by local conditions, the type of engine to be used and the service of the vessel. Broadly speaking, the following are particularly suitable for Voith-Schneider propulsion:

Shallow-Draught Vessels.—About 75 per cent of the vessels fitted with Voith-Schneider propulsion have a draught of 6 feet or under. The problem of getting the requisite swept area rules out the screw, particularly if the vessel is to be used for towing purposes, even in tunnel construction. Paddles at the side, stern or quarter would be suitable with steam engines, but complicated with Diesel or electric drive, while the maneuverability, particularly at low speeds, is inferior. With the Voith-Schneider propeller, the diameter can be increased to compensate for the shortness of blades, thereby ensuring the correct swept area and revolutions. It is sometimes stated that the Voith-Schneider propeller is particularly liable to blade damage in shallow-draught ships, but this problem has been successfully tackled by the designers. The blade shafts in passing through the runner wheel are now enclosed in a complete cylinder so that should severe blows be given to the blades and even if the blade be broken off at the neck, water can only rise into the cylinder, but not into the runner wheel itself. The blades are weaker than the shafts and will, therefore, give before any damage can be transmitted to the internal parts. In severe grounding, with the blades revolving and striking on rock, internal damage may be done, but such a grounding would be equally disastrous to a screw. The tips of the blades are always above the level of the keel and the blades can be changed easily and quickly if necessary. It is also customary to fit some form of skeg protection, as a precautionary measure, when operating in rivers with sunken logs and rocky ledges. One vessel operating on the Niger has now been in continuous service for nearly two years, and though submerged objects have been struck, no damage has been done and no replacements or spares used. This has been the general experience with shallow-draught ships, while there has been one notable exception where the force of the blows not only damaged the blades, but bent the blade shafts and broke down certain welding on the runner wheel. Precautions have now been taken against the dangers known to exist, with perfectly satisfactory results.

Dual-Purpose Vessels.—Salvage vessels requiring high power for pumps or deck machinery could use the one main engine for all purposes with an all-through shaft driving generators, pumps or other machinery. The control of the vessel at slow speeds, or when stopped and operating in deep water in a tideway or seas, would be fully assured with Voith-Schneider propulsion,

since any power required could be given to the propeller, leaving the residue to be utilized for other purposes at the same time. No other system of propulsion would ensure such complete control of the ship when operating under the difficult conditions constantly recurring in salvage work. Fire floats could utilize the one main engine for propulsion and pump work. The draught could be reduced by increasing the diameter of the propeller and giving the float more beam. This would be of great value in river or tidal waters to get closer to the seat of the fire, so increasing the effective power of the water streams. The control of the fire float would also be greatly enhanced, in that the effect of the reaction of the water jets tending to throw the float out of position would be quickly counteracted. Floating cranes are especially suitable for Voith-Schneider—there being now seven such craft fitted—since it enables such craft to operate under any conditions without additional help from tugs and to work in places where the normal self-propelled crane could not operate, except under considerable difficulty and with great delay.

Vessels Operating in Restricted Waters.—Voith-Schneider propulsion gives the best control of the ship, and also gives complete control at low speeds and when stopped. The ship can turn on one spot, go alongside or get away from quays with safety even if there is room only for her bare length, and can stop from full speed in considerably less time than with screw or paddle. The maneuverability when going astern is the same as for ahead motion. Valuable time can therefore be saved in congested waters and the safety factor of the ship be considerably increased.

Tugs.—This class of ship has two distinct subdivisions, viz., the ship-handling and the barge-handling tug. Common to each is the necessity of having a propeller with a good tow-rope pull. This demands as large a swept area as is consistent with the draught, power and type of engine to be installed. Each also requires a high degree of maneuverability; the one to get quickly and easily into position to make fast to the ship and the other to pick up a barge or train of barges and drop them at probably different wharves. The ship-handling tug, when fast, must be capable of orientating herself to give the desired pull for change of direction to her tow. This, particularly for a stern tug operating in strong tidal waters, is no light task and many tug owners prefer the paddle vessel for the stern, if not for the bow, tugs, since they have a turning point about their middle length and so can maneuver quicker to give the desired pull. The Voith-Schneider propeller satisfies all these requirements. The swept area can be increased by enlarging the blade-orbit diameter, so giving a good tow-rope pull which also allows of considerable reduction in draught, thereby increasing the tug's sphere of operation. With regard to maneuverability, the full thrust and power of the engines can be put at right angles to the ship, so that without any movement ahead or astern, she can turn through 90 degrees in less than 10 seconds. This is of great advantage to a ship-handling tug and to the safety of her tow. Many tug owners will not use the Diesel engine despite its economy in operation and stand-by costs, and one of the main reasons is that this type of engine is essentially non-flexible; that is to say, if the tow or pull on the propeller is too heavy the revolutions will be reduced. This reduces the output of the engines, which, in turn, reduces the effective pull. Diesel-electric drive overcomes to a certain degree this inflexibility, but adds to the machinery complications and has not been greatly adopted. There is also the comparatively high loss in transmission power from the main engines to the propeller shaft. Steam is comparatively flexible and the power given can be varied within wide limits. It is costly for stand-by, must bunker more frequently

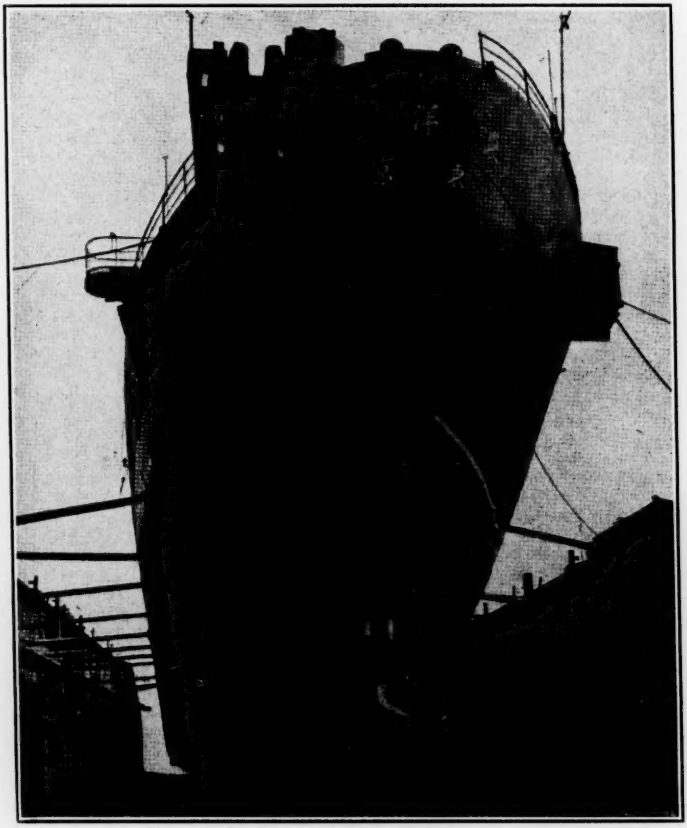


FIGURE 6.

and has not the radius of action of the internal-combustion engined vessel; smoke is also a source of annoyance in ship-handling tugs. In the case of the Voith-Schneider propeller driven by a Diesel engine, if the pull is too heavy for the propeller at full pitch the pitch can be reduced so that the full revolutions are maintained by the engines and full output is given to the tow with the highest efficiency of tow-rope pull.

Ferries.—These mostly operate in restricted waters and must constantly come alongside and get away from quays or berths. Increased maneuverability, therefore, decreases time of passage and has a beneficial effect on the running costs, especially where the service is continuous throughout the year. A paddle vessel to come alongside a pier at right angles to her course, must make a large sweep and approach the pier in a parallel direction, thereby adding to her steaming distance, time and running costs, while the screw vessel is little better in handling and less efficient in propulsion if shallow draught is an essential. The Voith-Schneider propelled ship can approach her berth at right angles and when in position swing in under perfect control, cutting down time and costs. Further, Diesel engines can be used, and if the ferry is for vehicular traffic, the deck space, and so the earning capacity of the ship, can be considerably increased. The Dundee ferry *Abercraig* is stated to have 80 per cent more deck space than a similar steam paddle ferry could give.

An additional feature of Voith-Schneider propulsion is that single-ended vessels may be used on services where previously double-enders have been necessary, so that the vehicles may drive on and off in one direction. The single-ender must be turned 180 degrees twice on every alternate passage, and the time taken with screws or paddles and the poor control of the ship when going astern has previously ruled them out. Unfortunately, the double-ender is extremely inefficient and, with screws, requires up to about 70 per cent more power for the same speed as a similar single-ender; or, conversely, the speed on the same power is 15 per cent to 20 per cent less. With Voith-Schneider propulsion, however, the ship can turn 180 degrees in less than a minute, so that the time lost in turning on alternate trips is amply compensated for in the increased speed, while there is perfect control of the ship under stern way. Therefore, except in very short passages or in certain special cases, the single-ended vessel may be used for such ferry services. An additional advantage of having a single-ended vessel is that she can be used for excursion or other purposes, thereby extending her utility of operation on the most economical basis.

Special Installations.—The better control of the Voith-Schneider ship in bad weather makes this system admirably suited for naval coastal-patrol boats, for convoy vessels and for minesweeping craft, which have to work in heavy weather and must, of necessity, have the highest maneuverability. An interesting application of such a type is an aircraft rescue vessel, having a movable crane on a track at the after end. Normally, the propellers are controlled in the usual manner from the bridge, but when the crane is in operation over the stern, the propellers and the ship are controlled electrically from the crane pedestal. Complete co-ordination of ship and crane movements is thereby assured. The Japanese cable-laying ship *Toyo Maru,* shown in Figure 6, has a normal arrangement of two screws and a rudder for steaming to and from her cable ground. When over her cables, or working cables, the main engines are cut out and the ship is propelled and controlled by one Voith-Schneider propeller of 1200-millimeter blade-orbit diameter, driven from an electric motor of about 100 HP. The ship is kept steady on her course and the effect of wind and weather counteracted more effectively

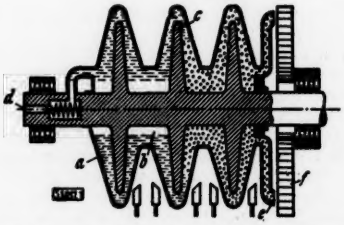
than is possible at these low speeds with the normal arrangement of screws and rudder. The natural growth of this idea is for sea-going ships of large dimensions to be fitted with a Voith-Schneider propeller in addition to the two outside screws. This will give a certain increase in power and steering when on long runs, and when entering and leaving port, and going through channels, the two main screws can be cut out and the ship propelled and steered by the Voith-Schneider propeller.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

A FRENCH ROTATING BOILER.—Reprinted from the November, 1939, issue of "Combustion," published by Combustion Publishing Co., 200 Madison Ave., New York, N. Y.

"Wärmewirtschaft" of August, 1939, describes a revolving boiler and turbine unit of French design which has undergone tests by the French military authorities. The operating principle is similar to that of the Hüttner turbo-boiler; but, instead of both the boiler and the turbine revolving in opposite directions, the turbine wheel is stationary and only the boiler revolves, the generator being mounted on an extension of the boiler shaft. The arrangement appears much simpler than the Hüttner design.

Referring to the sketch, the series of hollow disks *a* are mounted on a shaft. These communicate by means of passages *b*, close to the shaft. Within the hollow disks are flat disks *c*, attached directly to the shaft, which serve as partitions around which the fluid is obliged to pass. Feedwater is introduced through the hole *d* in the shaft and enters the first of the hollow disks. Superheated steam leaves the last of these disks and, through passages and nozzles *e*, impinges on the turbine blades *f*. The nozzles are provided with valves. The turbine wheel is rigidly attached to the housing and the reaction between the impinging steam and the stationary blades causes the boiler to rotate.



SKETCH OF BECHARD ROTATING BOILER-TURBINE UNIT.

Heat is applied from below and the hot gas is baffled so that its flow is counter to that of the working fluid within the boiler; that is, the last hollow disk, containing superheated steam, is exposed to the hottest gas.

The lower half of the boiler is filled with water, and heat applied. Steaming begins in the last (right-hand) hollow disk and as the pressure rises the water is forced back into the left-hand disks. When the steam valves

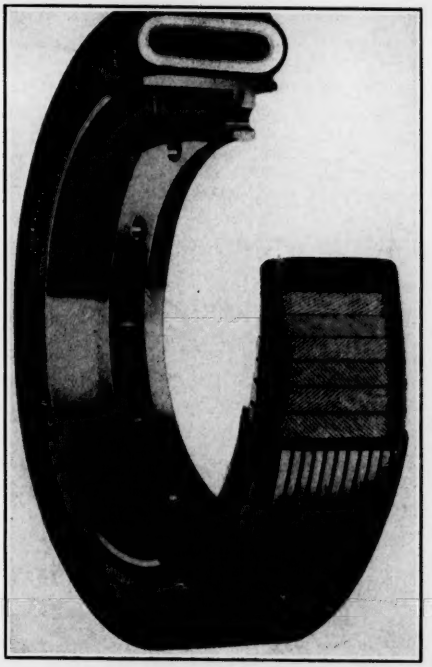


FIGURE 1.—PNEUMATIC ELEMENT OF AN EXPANDING CLUTCH.

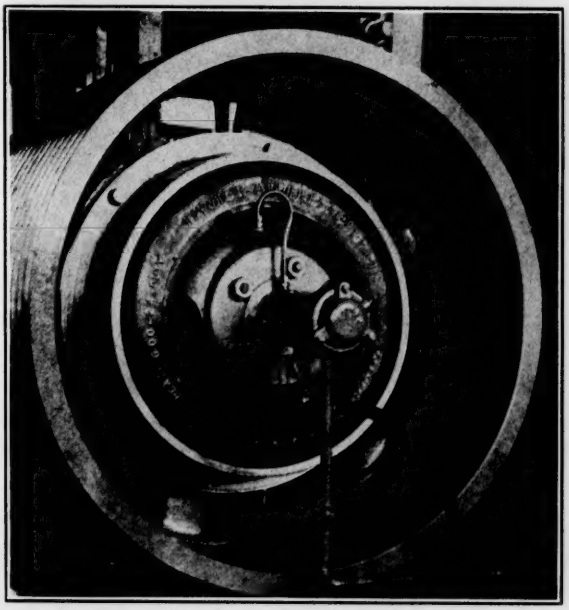


FIGURE 2.—CLUTCH BUILT INTO A V-BELT PULLEY.

FIGURE 3.—MARINE REDUCTION GEAR WITH RUBBER CLUTCH.

ahead of the nozzles are opened the boiler begins to revolve and the centrifugal action forces the water toward the periphery of the disks, while steam forms at the inner portions. The combination of centrifugal force, flow of steam and difference in temperature produces circulation of the fluid from the colder to the hotter part of the boiler. A feed pump is not required.

The unit tested produced 50 HP. at 425 pounds pressure and 1800 RPM.

THE AIRFLEX CLUTCH FOR DIESELS.—"Motorship and Diesel Boating," 192 Lexington Ave., New York, N. Y., September, 1939. The Airflex clutch has been employed in a number of Diesel installations, including main propulsion units of tugs.

While the old adage "there is nothing new under the sun" may be true from an academic standpoint, occasionally an idea is developed, often having its inception in a more or less accidental or incidental action, that causes us to doubt it.

An example of this is a pneumatic, rubber clutch that has been announced by the General Tire & Rubber Company. The idea that led to the development of this clutch was suggested by observing the manner in which the so-called squeegee-tread automobile tires adhere to wet, slippery pavements. Since all plate and cone type clutches used for power transmission depend upon the quality of adhesion for their action, it was logical to connect the idea of tire action with clutch action. Further investigation of the action of the multi-vaned tire treads showed that under braking pressure the ribs of rubber squirmed into a serpentine form and clung to the road surface with a high degree of adhesion.

From this point it was but a step to the multi-vaned rubber clutch, the working surface of which, with its rubber ribs, clings to steel with a much higher friction coefficient than asbestos or other clutch linings.

The Airflex clutch may be likened to a pneumatic tire attached to a driving member and working against a steel driven member, the clutch being engaged by inflating the tire and disengaged by deflating it. An idea of its construction may be obtained from the accompanying photographs. There are two types of this clutch, the expanding and constricting. Figure 1 shows the pneumatic element of the expanding type, in which it may be seen that the construction is similar to that of a tire, there being six plies of tire fabric enclosed in heat-resisting rubber. The outer surface is made in the form of a ribbed tread, while the tube is pre-molded and coated on the inside to resist oil vapor that might be in the air coming from the compressor. The rubber expansion member is vulcanized to a brass rim which bolts to a spider on the driving shaft.

In Figure 2 is shown a completely assembled clutch built into a grooved pulley for a V-belt drive. Here may be seen the air line by means of which the clutch is inflated, the connection to the clutch being made by means of a rotary seal. In this connection it is interesting to note that the capacity of the clutch is variable and can be regulated by the air pressure in the pneumatic member.

In the constricting type of clutch the pneumatic member surrounds the driven member and expands inwardly to grip it. Two distinct types of lining are used, on both the expanding and constricting types of clutches. When excessive slippage is encountered or where loads are to be picked up gradually, friction lining is used, but where slippage is not great and engagements not too frequent the ribbed rubber tread is used. The 40-inch clutch is the largest

made up to this time and is used on marine applications. It has a capacity of 3000 HP.

In Figure 3 is shown a 30-inch rubber clutch of the constricting type, used in connection with a reducing gear on the 950-HP. *Bull Calf*. In a recent test of this clutch, it was found that after 1400 consecutive reversals, putting the engine from full ahead to full astern in three seconds, not even the high spots had been worn off the lining.

It is claimed that slight misalignment does not affect the action of the clutch, and that the flexibility of the rubber has a decided damping effect on vibration.

DURAMOLD—A STRUCTURAL MATERIAL.—"The Aeroplane," Temple Press, Ltd., 175 Picadilly, London, England, July 26, 1939.

Regular readers of "The Aeroplane" will remember that in a recent discussion of Colonel Virginius Clark's work in the development of slotted wing-tips, reference was made to a new structural material, Duramold, which had been used by Colonel Clark.

Further information about this material has now been given by Colonel Clark before the World Engineering Congress of the S. A. E., New York, on May 26. A summary appears in "Aero Digest" (New York).

Duramold has a specific gravity of from .5 to .9, which can be accurately controlled within plus or minus 3 per cent. Within this range of specific gravity the strength and elastic modulus vary roughly as the density. In its final form Duramold is sufficiently non-hygroscopic and free enough from attack by fungi and the like for all practical requirements.

After seven weeks of complete immersion, specimens which have a ratio of net area to total area a thousand times as great as the ratio that exists in aeroplane shells have increased in weight by less than 1 per cent, with negligible change in dimensions, no deformation or change in physical characteristics. Duramold is not isotropic (that is, its strength is not the same in all directions, as it is stronger in some directions than others), but Colonel Clark considers that this is not a disadvantage in practice. This suggests that wood or similar fibrous material is the reinforcement.

SOME PROPERTIES.—A TABLE TO SHOW APPROXIMATE VALUES FOR DURAMOLD IN POUNDS PER SQUARE INCH DIVIDED BY (1000 × SPECIFIC GRAVITY OF MATERIAL).

Duramold Type	*Direction of Applied Load*	*Tension*	*Compression*	*Young's Modulus T. & C.*
I	Optimum	25.75	13.95	3060
I	90 Degrees to Optimum	4.72	7.70	714
II	Optimum	22.73	13.03	2730
II	90 Degrees to Optimum	7.75	8.60	1053
III	Optimum	19.69	12.08	2380
III	90 Degrees to Optimum	10.80	9.51	1395
IV	Optimum	16.75	11.22	2040
IV	90 Degrees to Optimum	13.87	10.40	1732
	Shear (Optimum)	10.4		

As there is no hysteresis within the proportional limits, in which the tension is practically the same as the ultimate strength, there is no creep.

For purposes of comparison, Colonel Clark has calculated the strengths of four cylinders with different types of construction. In each instance the diameter is 60 inches, the weight per foot run is constant, and the space between the transverse frames or rings is 30 inches.

Such a cylinder with a smooth skin of aluminium alloy (17 S.T.) with a skin of .032 inch thick reinforced by flanged Z-section longitudinal stringers ⅞ inch × ½ inch × .050 inch with a spacing of 6 inches and a total stiffener area of 3.23 inches would support a load of 63,000 pounds.

An unstiffened aluminium alloy cylinder of the same weight per foot run would support 30,000 pounds.

A cylinder of reinforced synthetic resin (Bakelite with fabric or cord) would support 8000 pounds.

A Duramold cylinder of material between Types 2 and 3 would support 113,000 pounds, or 14.1 times as much as the plastic cylinder and 80 per cent more than the reinforced high-strength aluminium-alloy cylinder.

Colonel Clark claims that Duramold does not support combustion and that for a given weight per unit area a shell of Duramold after a fire will support loads many times those that Duralumin could.

Duramold is not subject to corrosion. Its energy-absorption characteristics are excellent. Its damping in vibration is about five times that of metal.

Another claim of Colonel Clark's is that, according to calculation based on wind-tunnel tests at fairly high Reynolds Numbers, the use of Duramold for a fuselage, wing and fixed tail unit results in about 25 per cent less power being required for a given top speed compared with an all-metal aeroplane with projecting rivet-heads, lap joints and the wave and wrinkles which are present in the air and, or after, service.

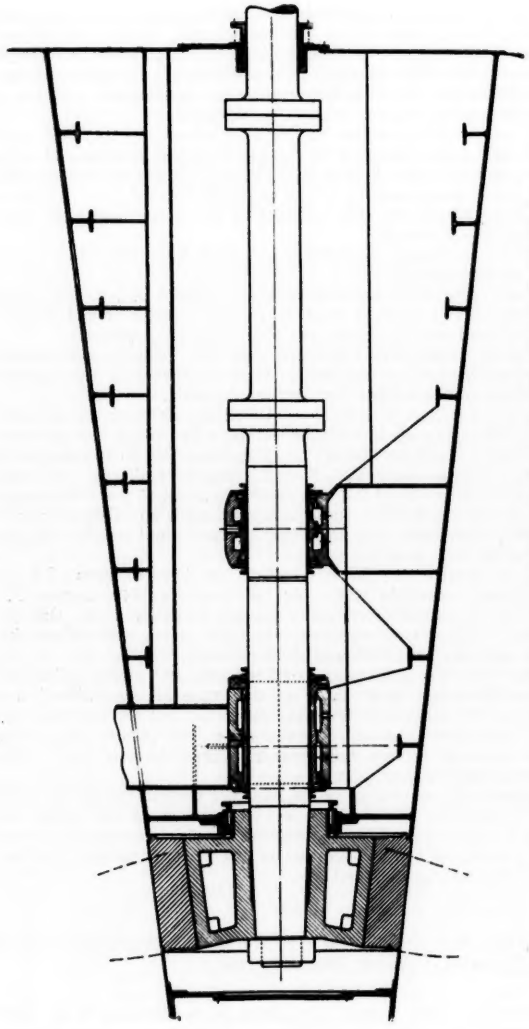
Duramold has been tested for its reactions to sharp changes of temperature. Panels are soaked in water for two hours at 140 degrees F. and immediately put in a temperature of 70 degrees F. below zero. During and after repeated cycles of such treatment there was no sign of serious change. Similar tests with dry panels showed similar results.

Concurrently with the development of Duramold and of the technique and apparatus for producing parts made of this material, evolution has been necessary of new principles of structural design so that the material may be disposed and utilized in the most effective manner. At present details regarding the basic material, process and apparatus cannot be published. Bakelite in various forms plays a large part.

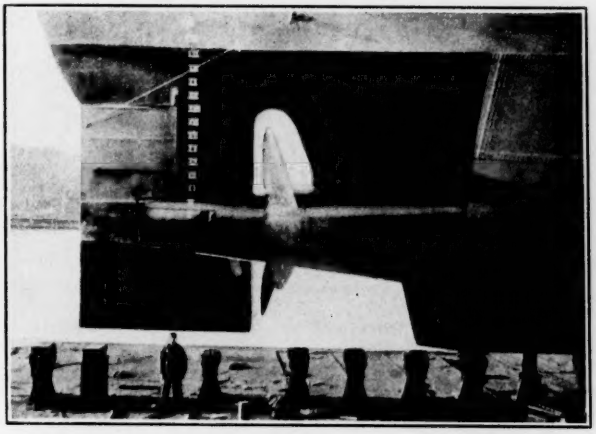
There is practically no change in the moisture content during the molding operations. A complete half-shell, 40 feet long and up to 500 square feet in area, may be formed with smooth, permanent, simple or compound, curvature with the same quick and simple operation as that which permanently unites the various basic elements of the shell.

TANKER WITH NEW FORM OF STERN.—" Shipbuilding and Shipping Record," London, England, August 3, 1939.

The motor tanker *Nike*, recently completed by Götaverken A/B., Gothenburg, to the order of Rederi A/B. Transoil, Gothenburg, is the first vessel to feature the new type of stern construction designed by Mr. Folke Seldén, chief naval architect of Götaverken. The new form, for which patents have been applied for in all shipbuilding countries, was originally designed to avoid



TUNNEL ARRANGEMENT OF THE "NIKE" SHOWING PROPELLER BOSSING AND STERN TUBE DETAILS.



PROPELLER BOSSING AND RUDDER ARRANGEMENT.

drydocking, by making stern tube details accessible from inside the ship, and also results in higher propeller efficiency.

The *Nike*, which is the ninth vessel delivered by the Götaverken yard this year, is propelled by an 8-cylinder single-acting, four-stroke Götaverken-B. & W. Diesel engine developing 5100 IHP. The engine has cylinders 740 millimeters diameter at a piston stroke of 1500 millimeters. The principal particulars of the vessel are:

Length, overall, feet and inches	483– 9
Beam, molded, feet and inches	59– 0
Depth, feet and inches	35– 6
Draught, feet and inches	27–10⅜
Gross tonnage, tons	8,400
Dead weight, tons	12,550
Speed, knots	13

As may be seen from the illustration opposite, the under-water part of the hull around the propeller shaft is enclosed in a circular framework or bossing which is directly connected to the plating around the stern frame. The rudder bearing is thus directly accessible from inside the ship by means of a ladder. During trials, a number of guests descended into this space just aft of the whirling propellers.

The propeller boss, which forms part of the streamlined framing, has been enlarged to a diameter of about 6 feet and is so constructed that only the blades are in contact with the water. The stern tube is run in a bath of oil and a Vickers duplex type Vista gland, supplied by the B. R. Vickers (Leeds) Engineering Co., Ltd., is fitted to a projection on the propeller boss and runs inside a trunk. This construction may be seen in the drawing.

It is claimed for the new construction that all parts of the propelling machinery and steering apparatus are accessible without docking the ship. At a luncheon held on board during trials, a tribute was paid to Mr. Rolf Sörman, manager of the owning company for his progressive spirit in trying out new ideas.

The rudder trials, awaited with special interest on account of the wedge-like construction of the rudder, showed that the rudder could be moved from hard over to hard over in 17 seconds against the ordinary 25-30 seconds required.

The current made it impossible to measure the speed exactly, but, with the ship fully loaded and without forcing the engine, 13.6 knots were attained, that is, 0.2 knots more than with sister ships previously delivered. Tank tests have shown a saving in horsepower of about 7 per cent for this speed and the full-size tests thus seem to confirm these tank tests.

Accommodation of the *Nike* is of an unusually high standard, even if compared with the high general standard of tankers. The captain's rooms may be compared with the suite de luxe of a passenger liner, and officers, as well as the remaining members of the crew, have been cared for in a manner never before attempted. The crew, for instance, has large and comfortable mess-rooms and, moreover, a large smoking room containing paintings, radio set, oak furniture and upholstery.

ASSOCIATION NOTES.

ELECTION OF OFFICERS.

The following have been elected officers of the Society for the calendar year, 1940:

President:
Captain Henry Williams (CC), U. S. Navy.

Secretary-Treasurer:
Lieut. Commander Guy Chadwick, U. S. Navy.

Council:
Captain Hollis M. Cooley, U. S. Navy.
Captain Lybrand P. Smith, U. S. Navy.
Commander Frederick W. Pennoyer, Jr., U. S. Navy.
Commander Edmund E. Brady (CC), U. S. Navy.
Commander Charles J. Odend'hal, U. S. Coast Guard.
Mr. George B. Ferrier.
Mr. Harold K. Beck.

ANNUAL BANQUET.

The Annual Banquet of the Society will be held on Friday, April 5, 1940, at the Willard Hotel in Washington, D. C. A notice giving full information has been addressed to members. The speakers will prove outstanding in every way.

INVITATION.

The Houston Engineers Club extends an invitation to the non-resident members of the American Society of Naval Engineers to make use of its Club quarters and facilities, located at 2615 Fannin St., Houston, Texas, and to participate in the luncheon meetings held on alternative Tuesdays at the Rice Hotel in that city.

MEMBERSHIP.

The following have joined the Society since the publication of the November, 1939, JOURNAL:

NAVAL.

Armstrong, L. W., 2 Nassau Road, Upper Montclair, N. J.

Barker, W. C., Lieutenant, U. S. N. R.; Chief Engineer, MS *Western Sun;* residence, 1770 Euclid St., Beaumont, Texas.

Brierly, D. S., Director, Maintenance and Repair, U. S. Maritime Commission; residence, The Westchester, 4000 Cathedral Ave., Washington, D. C.

Eccles, Henry E., Lieutenant Commander, U. S. Navy.

Gawne, James O., Captain (CC), U. S. Navy.

Hurley, M. J., Chief Machinist, U. S. Navy.

Jones, H. McCoy, 1 Blackistone Road, Westmoreland Hills, Friendship Station, D. C.

Kirkpatrick, John E., Lieutenant, U. S. N. R., Box 1020, Tulsa, Okla.

Libby, Ruthven E., Lieutenant Commander, U. S. Navy.

McManus, J. D., Asst. Chief Engineer, Walworth Co., Huff Avenue, Greensburg, Pa.

Noble, Warren, Lieutenant Commander, U. S. N. R., Wardman Park Hotel, Washington, D. C.

Olds, Hugh W., Commander, U. S. Navy.

Rickover, Hyman G., Lieutenant Commander, U. S. Navy.

Robertson, K. C., Apartment O-117, 1415 Clearview St., Philadelphia, Pa.

Rose, Edwin L., Lieutenant, U. S. N. R., Chief Engineer, Waterbury Tool Company, Waterbury, Conn.

Steinkuller, B. W., 8714 Prospect Ave., Chestnut Hill, Philadelphia, Pa.

Williams, Henry, Jr., Lieutenant, U. S. Navy.

CIVIL.

Bayerlein, R. W., Sales Manager, Heavy Machinery Division, Nordberg Mfg. Co., Milwaukee, Wis.

Brown, Harry S., President, Foster Wheeler Corporation, 165 Broadway, New York, N. Y.

Campbell, Albert F., Timken Roller Bearing Company, 823 Transportation Building, Washington, D. C.

Charles, David S., Engineer, Bureau of Engineering, Navy Dept., Washington, D. C.

Crooke, Raymond E., Asst. General Manager, Ford Instrument Company, Inc., Rawson St. and Nelson Ave., Long Island City, N. Y.

Davis, Richard H., Asst. Manager, Marine Division, Worthington Pump and Machinery Corporation, Harrison, N. J. Residence, 9 Roswell Terrace, Glen Ridge, N. J.

Denny, Edward L., Technical Manager, William Denny and Bros., Ltd., Engine Works, Dumbarton, Scotland.

Devine, R. F., Jr., President and General Manager, Erie Forge Company, Erie, Pa.

Engel, Francis H., Radio Research Engineer, R. C. A. Mfg. Co., 724 14th St., N. W., Washington, D. C.

Flick, Frank, Marine Sales Manager, The Buda Company, Harvey, Ill. Residence, 1120 South Euclid St., Oak Park, Ill.

Friend, Robert E., President, Nordberg Mfg. Co., Milwaukee, Wis. Residence, 3073 South Chase Ave., Milwaukee, Wis.

Grieshaber, Emil, Chief Engineer in Charge Engineering and Designing Departments, Nordberg Mfg. Co., Milwaukee, Wis. Residence, 2928 South Lenox St., Milwaukee, Wis.

Grogan, H. H., in charge Maintenance, Coast Guard Headquarters, Washington, D. C.

Haas, Hugo H., in charge Diesel Engineering, War Dept. Residence, 78 Buena Vista Terrace, S. E., Washington, D. C.

Haley, D. Norman, Asst. Engineering Draftsman, Bethlehem Steel Co., Shipbuilding Div., Quincy, Mass. Residence, 10 Thompson St., Quincy, Mass.

Hodgkinson, F. P., Waterbury Tool Company, Waterbury, Conn.

Jacocks, Thomas B., General Electric Company, 806 15th St., N. W., Washington, D. C.

Jahn, Raymond F., Chief Engineer, Ford Instrument Company, Inc., Rawson St. and Nelson Ave., Long Island City, N. Y.

Johnson, William J., Jr., Designing Engineer, Nordberg Mfg. Co., Milwaukee, Wis. Residence, 5612 W. Brooklyn Place, Milwaukee, Wis.

Lockwood, W. G., Lieutenant Colonel, U. S. A. (R.), American Locomotive Co., Barr Building, Washington, D. C.

McKinnon, H. D., in charge Marine Developments, Aluminum Company of America, Wearever Building, New Kensington, Pa.

McMullin, A. R., Manager, New York Office, Nordberg Mfg. Co., 60 East 42d St., New York, N. Y.

Miller, W. S., Special Representative, York Ice Machinery Corporation, 1238 N. 44th St., Philadelphia, Pa.

Nelson, W. F., 75 Mt. Vernon, West, East Weymouth, Mass.

Northam, J. C., Worthington Pump and Machinery Corporation, Washington, D. C. Residence, 2952 Newark St., N. W., Washington, D. C.

Priebe, C. J., in charge Federal Dept., SKF Industries, Front St. and Erie Ave., Philadelphia, Pa.

Shepard, Thomas H., Jr., Electrical Engineer, U. S. Maritime Commission. Residence, 1026 16th St., N. W., Washington, D. C.

Swan, James, Principal Marine Engineer, Bureau of Marine Inspection and Navigation, U. S. Maritime Commission. Residence, 3601 Connecticut Ave., Washington, D. C.

Thompson, Edw. A., Mechanical and Hydraulic Engineer, Waterbury Tool Company, Waterbury, Conn.

Thompson, Henry H., Westinghouse Electric & Mfg. Co., 328 Washington Building, Washington, D. C.

Welsh, Joseph H., civilian in charge, Electrical Design, Navy Yard, New York, N. Y.

Willett, Warren P., Mechanical and Hydraulic Engineer, Vickers, Inc. Residence, 113 Allegheny Ave., Takoma Park, Md.

ASSOCIATE.

Bird, Albert F., Engineer, Turbine and Gear Section, Bureau of Engineering, Navy Dept., Washington, D. C.

Hill, James P., Diesel Engineer, 343 Warren St., Baltimore, Md.

Mederos, Dennis F., Sales Engineer, Walworth Company. Residence, 86 Park Ave., South Weymouth, Mass.

Whitten, Leslie H., Manager, Washington Office, Graybar Electric Co., 1119 14th St., N. W., Washington, D. C.